MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

AD-A156 077

AN ANALYSIS OF
THE SPECIALIZED UNDERGRADUATE
PILOT TRAINING PROGRAM
(SUPT)

THESIS

Joseph B. Niemeyer   Michael D. Selva
Captain, USAF   Captain, USAF

AFIT/GST/OS/85M-9

DTIC
FILE COPY
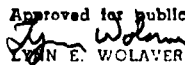
REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	Approved for public release; distribution unlimited.
4. PERFORMING ORGANIZATION REPORT NUMBER(S) AFIT/GST/OS/85M-09	5. MONITORING ORGANIZATION REPORT NUMBER(S)

6a. NAME OF PERFORMING ORGANIZATION School of Engineering	6b. OFFICE SYMBOL (If applicable) AFIT/ENS	7a. NAME OF MONITORING ORGANIZATION
6c. ADDRESS (City, State and ZIP Code) Air Force Institute of Technology Wright-Patterson AFB, Ohio 45433		7b. ADDRESS (City, State and ZIP Code)

8a. NAME OF FUNDING/SPONSORING ORGANIZATION	8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER

8c. ADDRESS (City, State and ZIP Code)	10. SOURCE OF FUNDING NOS.			
	PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT NO.
11. TITLE (Include Security Classification) See Box 19				

12. PERSONAL AUTHOR(S)
Joseph B. Niemeyer, Capt, USAF and Michael D. Selva, Capt, USAF

13a. TYPE OF REPORT MS Thesis	13b. TIME COVERED FROM _____ TO _____	14. DATE OF REPORT (Yr., Mo., Day) 1985 March	15. PAGE COUNT 169

16. SUPPLEMENTARY NOTATION

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB. GR.	Training, Pilots, Pilot Studies, Jet Training
05	09		Planes, Flight Training, Simulation, and Mathematical Models.

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

Title: AN ANALYSIS OF THE SPECIALIZED
UNDERGRADUATE PILOT TRAINING
PROGRAM (SUPT)

Thesis Chairman: James R. Coakley, Major, USAF

Approved for public release: IAW AFR 190-17.

LYNN E. WOLAVER   1 May 85
Dean for Research and Professional Development
Air Force Institute of Technology (ATC)
Wright-Patterson AFB OH 45433

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☒ DTIC USERS ☐	21. ABSTRACT SECURITY CLASSIFICATION UNCLASSIFIED	
22a. NAME OF RESPONSIBLE INDIVIDUAL James R. Coakley, Major, USAF	22b. TELEPHONE NUMBER (Include Area Code) 513-255-3362	22c. OFFICE SYMBOL AFIT/ENS

DD FORM 1473, 83 APR   EDITION OF 1 JAN 73 IS OBSOLETE.

Since the approval of the Specialized Undergraduate Pilot Training (SUPT) concept in 1970, the Air Training Command has conducted several studies to determine the ability of this concept to satisfy Air Force pilot training requirements. By representing much of the data in mean value form, these studies failed to account for the variance between data points. To address this shortcoming, a simulation modeling approach was used employing the network structure of the SLAM simulation language with augmentation provided using FORTRAN inserts. Replacing mean values with random variates drawn from probability distributions where appropriate, and using the mean number of days required to complete all SUPT training requirements as a measure of effectiveness, this analysis determined the current program design can adequately satisfy Air Force requirements. A statistical analysis was conducted using the following design factors: the production goal, training program ratio, number of T-46 aircraft assigned, number of Tanker-Transport-Bomber (TTB) training aircraft assigned, number of T-46 simulators, and number of TTB simulators. The results of this analysis showed that the pilot production goal, the number of T-46 simulators, and their interaction have a statistically significant impact on primary training. The analysis also found that the production goal, the training phase ratio, the number of T-46 simulators, and their interactions have a statistically significant impact on the Fighter-Attack-Reconnaissance phase of basic training. An independent sensitivity analysis determined at what level each significant factor, given a fixed level for all other design factors, began to affect overall program operation.

AN ANALYSIS OF

THE SPECIALIZED UNDERGRADUATE

PILOT TRAINING PROGRAM

(SUPT)

THESIS

Presented to the Faculty of the School of Engineering

of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the

Requirements for the Degree of

Master of Science in Operations Research

Accession For	
NTIS GRA&I	☒
DTIC TAB	☐
Unannounced	☐
Justification	
By	
Distribution/	
Availability Codes	

Dist	Avail and/or Special
A/,	

Joseph B. Niemeyer, B.S.   Michael D. Selva, B.S.

Captain, USAF   Captain, USAF

March 1985

Approved for public release; distribution unlimited

Preface

The purpose of this analysis is to determine the ability of the current Specialized Undergraduate Pilot Training (SUPT) program design to satisfy Air Force pilot training requirements.

Since the SUPT program is in its development stage, a simulation model of the program was developed for use in this analysis. The model represents the operations of both the primary and basic phases of pilot training at all five UPT bases: Laughlin AFB, Williams AFB, Reese AFB, Vance AFB, and Columbus AFB. By using attrition, weather abort, and maintenance abort rate data expressed in terms of random variates drawn from probability distributions, the model creates a real-world, probabilistic environment within which system operation is observed. An understanding of the FORTRAN programming language and the SLAM simulation language is necessary to conduct further analysis with this model.

We would like to thank our faculty advisors, Major James R. Coakley and Lieutenant Colonel Palmer W. Smith, for their guidance and advice throughout the course of this analysis. We are also indebted to Major Wolf Gesch of the Operations Plans Directorate at Air Training Command Headquarters. Without his cooperation and assistance, this analysis would not have been possible. Last, but certainly not least, we would like to thank our wives, Louise and Karen, for their loving support through the good times and the bad.

Joseph B. Niemeyer   Michael D. Selva

ii

Table of Contents

iii

iv

List of Figures

List of Tables

AFIT/GST/OS/85M-9

Abstract

Since the approval of the Specialized Undergraduate Pilot Training (SUPT) concept in 1970, the Air Training Command has conducted several studies to determine the ability of this concept to satisfy Air Force pilot training requirements. By representing much of the data in mean value form, these studies failed to account for the variance between data points. To address this shortcoming, a simulation modeling approach was used employing the network structure of the SLAM simulation language with augmentation provided using FORTRAN inserts. Replacing mean values with random variates drawn from probability distributions where appropriate, and using the mean number of days required to complete all SUPT training requirements as a measure of effectiveness, this analysis determined the current program design can adequately satisfy Air Force requirements. A statistical analysis was conducted using the following design factors: the production goal, training program ratio, number of T-46 aircraft assigned, number of Tanker-Transport-Bomber (TTB) training aircraft assigned, number of T-46 simulators, and number of TTB simulators. The results of this analysis showed that the pilot production goal, the number of T-46 simulators, and their interaction have a statistically significant impact on primary training. The analysis also found that the production goal, the training phase ratio, the number of T-46 simulators, and their interactions have a statistically significant impact on the Fighter-Attack-Reconnaissance phase of basic training. An independent sensitivity analysis determined

at what level each significant factor, given a fixed level for all other

design factors, began to affect overall program operation.

AN ANALYSIS OF
THE SPECIALIZED UNDERGRADUATE
PILOT TRAINING PROGRAM
(SUPT)

.

I. Conceptualization

General Concern

In June 1980, the Secretary of the Air Force and the Chief of Staff
of the Air Force approved the concept of Specialized Undergraduate Pilot
Training (SUPT). Under this new approach to pilot training, all
students receive the same primary flight training using the Fairchild T-
46 aircraft. Several weeks prior to the completion of the primary
training phase, each student's flight training records will be evaluated
by a board composed of wing flight instructors. This board, the Advanced
Training Recommendation Board (ATRB), will review each student's
performance in the primary phase and will use this measure, the
student's personal desires, and Air Force pilot requirements to
determine to which phase of basic flight training each student will be
assigned. The basic flight training phase is divided functionally into
two different training programs. Those students who will ultimately fly
fighter, attack, or reconnaissance type aircraft upon completion of
pilot training will participate in the Fighter-Attack-Reconnaissance
(FAR) flight training program. In this program, they will accomplish
basic flight training in the supersonic Northrop T-38 Talon aircraft.
This aircraft is currently used in the basic flight training phase of
UPT. Those students destined to fly transport, tanker, or bomber

directed a staff study be conducted addressing the ability of the current undergraduate pilot training program to support Air Force requirements. The results of the study showed the current training system "<appeared> to have been built upon resources readily available rather than being aligned with USAF first-line aircraft." (6:5) Perhaps the most important finding of the study was:

> "It appears that future strategic efforts will be confined to a relatively small number of expensive, intricate aircraft applied singly or in small groups rather than a repetition of the multi-thousand plane efforts of WW II. In line with this philosophy, the proposed revised program is based on concentration of training efforts to produce well qualified air weapons experts rather than a large number of average aircraft drivers." [6:4]

Based on these and the other findings of the study, a program was proposed to "rejuvenate" the pilot training program. Approval of the program came on 3 July 1952, and by November 1952, the program was implemented. The first program step was to replace the Piper Cub with the T-34 as the primary screening aircraft. This replacement program lasted four years and by 1956, both the Piper Cub and the T-6 had been retired. The remainder of the plan called for the replacement of the T-28 by the T-37 for primary training and replacement of the T-33 with the T-38 for the basic phase. Nowhere in the plan were there any plans to replace the B-25 multi-engined trainer. Perhaps this was just as well because funds to procure a new multi-engined jet trainer were cut from the 1954 budget. (1:12-13)

Lieutenant General Charles T. Myers, Commander of ATC, sounded the death knell for the specialized dual-track training program when he

2-3

The single-engined advanced course consisted of 70 flying hours in the North American AT-6 Texan. The multi-engined advanced course consisted of 86 flying hours either in the AT-6 or the BT-13 aircraft. (1:8) This program continued throughout the Second World War, with a peak pilot production rate of 81,000 pilots a year being reached in 1944. At the end of the war, pilot production rates dropped to a mere 340 pilots a year. This drastic reduction was due, in part, to the large number of pilots trained during the war that were still on active duty. The number of pilots being trained notwithstanding, the new Air Training Command implemented a new specialized pilot training program in June 1946. Although the primary and basic phase remained relatively the same, the advanced phase was specifically divided into three categories: single-engine, twin-engine, and four-engine. The P/F-47 and P/F-51 were used in the single-engine phase, the B-25 in the twin-engine phase, and the B-17 and the C-54 in the four-engine phase. (1:8-9) (NOTE: In 1948, the Air Force changed the designation of their fighter aircraft from Pursuit (P) to Fighter (F). Hence, the notation P/F). In 1948, the four-engine advanced phase was terminated since its primary supporter, the Strategic Air Command, was satisfied with the quality of training conducted in the twin-engine phase. (1:10)

While the next milestone in the specialized pilot training program was the retirement of the F-51 as the single-engine advanced trainer. In December 1952, the F-80 Shooting Star jet fighter replaced the F-51. By early 1953, the T-33, the two seat version of the F-80, was the sole single-seat advanced trainer aircraft. (1:11)

While all these hardware changes were taking place, the commander of ATC focused his attention on the future of pilot training. He

II. Literature Review

Before discussing the development and application of the analytical techniques used in this study, it is important to review the events which lead to the adoption of the current program and the types of analyses and the analytical tools applied in past studies of Undergraduate Pilot Training. This review provides the analysts with a perspective on how pilot training problems were approached and allows the readers of this study to put its results in their proper perspective.

Historical Development

The history of Air Force pilot training has seen the program shift from a single-track system to a multi-track system and back to a single-track system. Prior to the Second World War, most American pilots were trained to fly single-engined, fighter type aircraft. (1:7) Due to the similarity of the pilot training received by these pilots, their training program, although not specifically termed single-track, could be categorized as single-track training. By 1940, as the U.S. prepared for war, the shortage of trained pilots resulted in the pilot training program being changed to a dual-track system. Under this program, each student pilot spent 10 weeks in the primary phase and accumulated 60 flying hours. In the basic phase, the student spent the same amount of time and accumulated 70 more hours of flying time. After completion of the basic phase, each student received advanced training in the type aircraft, either single-engined or multi-engined, to which he would ultimately be assigned.

Summary

    In this section the basics required for the formulation of the simulation model were discussed. The research objective is to provide the Air Training Command with an analysis of the ability of the current SUPT program design to satisfy Air Force pilot requirements. To assess this ability, the measure of effectiveness chosen for the analysis was the time required to complete the training requirements for each phase of training at each UPT base. By analyzing the effects changes in the levels of specific factors within the program model have on this measure, the functional relationships between these factors can be assessed and their impact on the overall performance can be determined. To conduct an accurate analysis of this problem, the entire analysis effort must have a logical and systematic flow. The description of the steps in a process analysis provide a blueprint for ensuring the realization of such a flow.
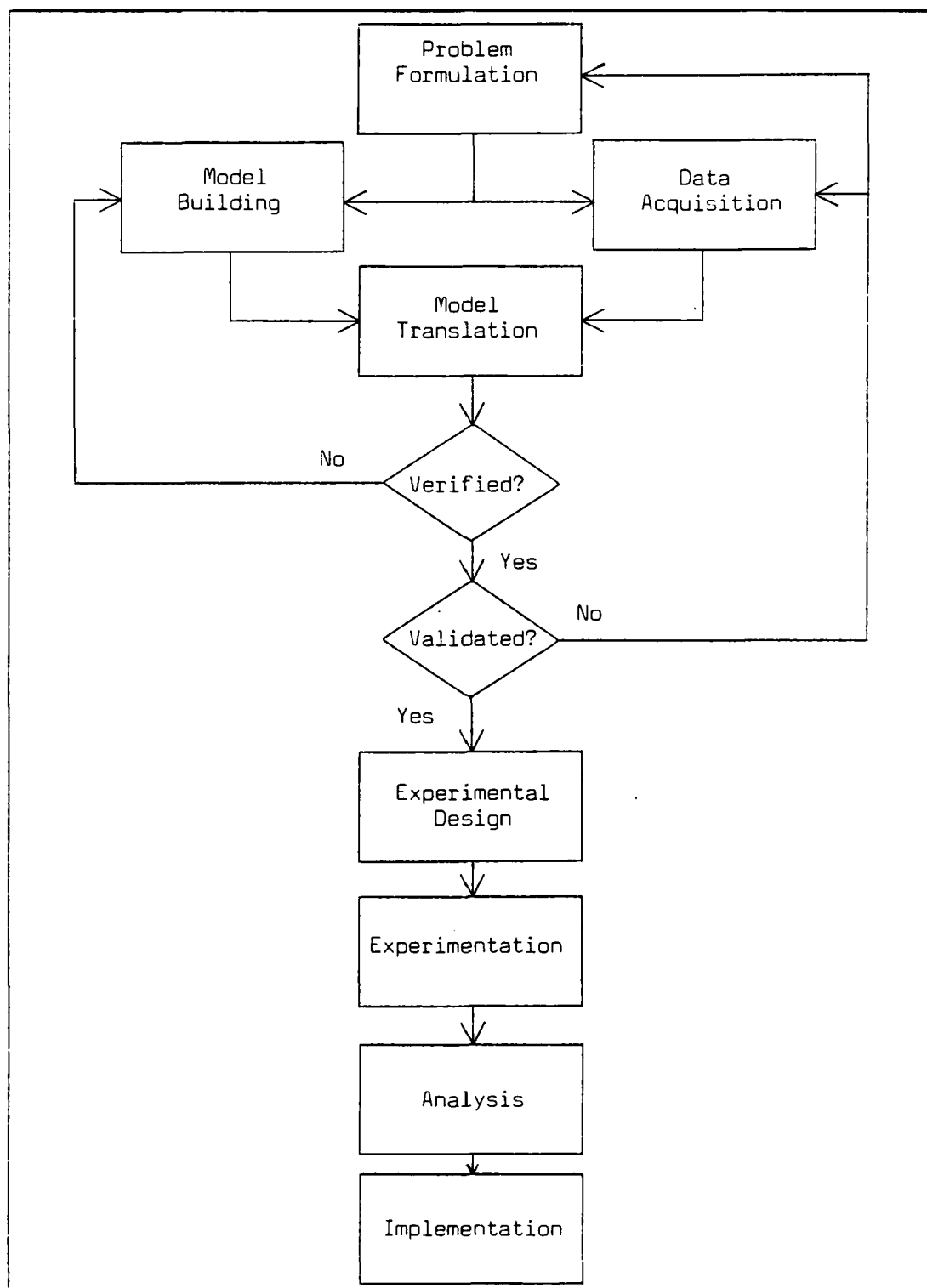
Figure 2. Process Analysis

5) Verification. This step actually is considered throughout the model development. Through verification one attempts to insure that the computer code performs as desired.

6) Validation. Like verification, validation is an on-going process. Through validation one attempts to insure that the simulation model accurately reflects the system being modeled.

7) Experimental design. The plan for running the model and performing an analysis which will give the desired information about the system is formulated.

8) Experimentation. The design is carried out.

9) Analysis. The output of the experiment is subjected to the statistical techniques chosen in the experimental design stage.

10) Implementation. The decisions which proceed from the analysis are put into practice.

Although there is tendency to follow these steps in a checklist fashion, the process analysis may become an iterative process requiring reaccomplishment of previous steps in light of new information or a different insight into system operation. Figure 2 illustrates how the process analysis is used to establish a logical approach to the conduct of the research.

required to accomplish all training requirements for each phase of training at each UPT base. This measure was chosen for two reasons. First, it provides information on the timeliness of the program as well as the program's ability to satisfy Air Force pilot requirements. Secondly, and perhaps most important, this measure is not unfamiliar to Air Training Command planners since it is one of the major benchmarks used to measure the effectiveness of the current UPT program. Although the SUPT program is a significant departure from the current UPT training concept, its overall goal has not changed, that of producing qualified pilots in a timely manner.

Process Analysis

Before describing the conduct of this analysis, it is important to emphasize the need for a logical, structured approach to the problem. The steps taken in the design, development, and testing of the model used in this analysis follow those suggested by Shannon (12), Gordon (5), and Banks (2). These steps are:

> 1) Problem formulation. Every study must begin with an accurate definition of the problem and the setting of research objectives that support the analysis of the problem.
>
> 2) Model building. In this step the abstract system is reduced to a set of logical and mathematical relationships.
>
> 3) Data acquisition. Here historical data used to support the analysis is collected and analyzed. Such data may be used to derive the probability distributions used in the model.
>
> 4) Model translation. Next, the conceptual model is translated in a computer language for processing.

1-9
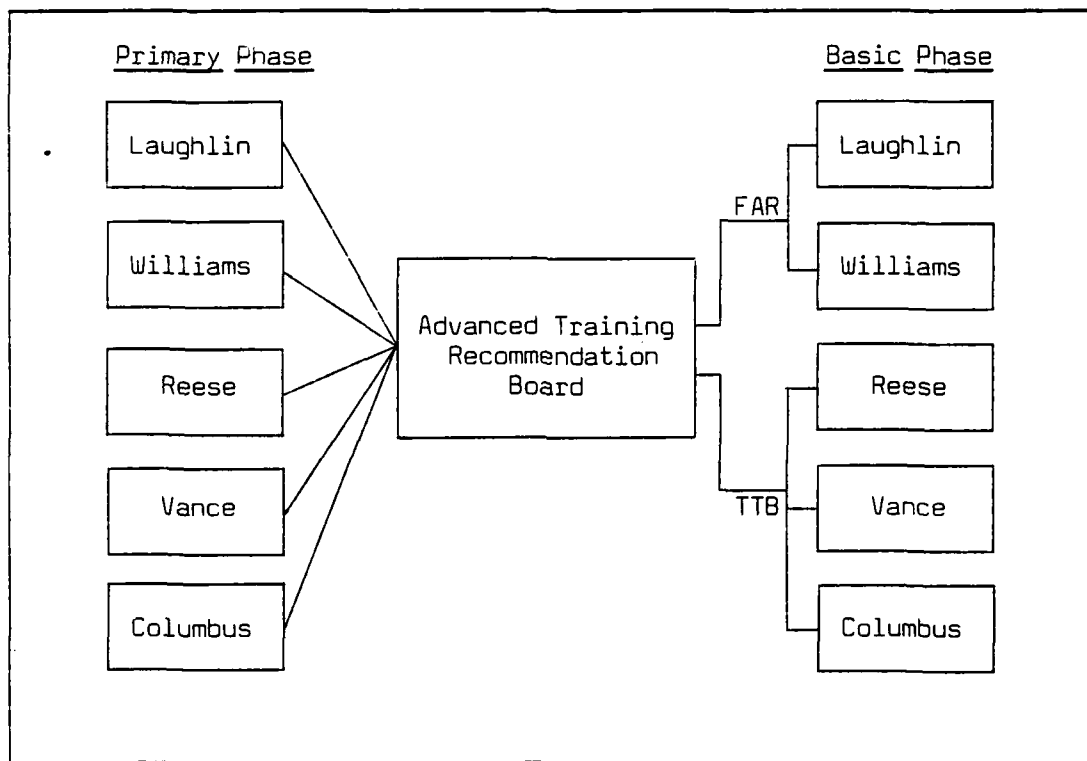
Figure 1. Outline of System Operation

training representative of the operational environment in which students will fly after graduation from SUPT. Conversion to SUPT and the TTBTS is expected to reduce the overall cost of pilot training through lower fuel consumption, improved maintenance capabilities, and the multiple crew training concept. (13:2)

Measure of Merit

Before beginning the model formulation process, the analyst must select the appropriate measure of merit for the system. This measure should allow him to use the model to realize the research objectives of the thesis.

The measure of merit chosen for this analysis is the mean time

will enter training every three weeks. The number of flights will be similar to the current number; six T-37/T-46 flights at each base, eight T-38 flights at Williams AFB and Laughlin AFB, and eight TTB flights at Columbus AFB, Vance AFB, and Reese AFB. Under the SUPT concept, all student pilots will receive common primary phase flight training to develop fundamental flying skills. Near the end of the primary phase, students will be evaluated by an Advanced Training Recommendation Board (ATRB) and routed to one of two specialized training tracks: Fighter-Attack-Reconnaissance (FAR) or Tanker-Transport-Bomber (TTB). This selection will be based on USAF manning requirements, demonstrated flying skills in relation to mission requirements, and individual preferences (13:1). After the ATRB, if a student selected for the TTB track is stationed at a base with TTB aircraft, then he or she will enter the next available class at that base. Otherwise, that student will make a permanent change of station (PCS) move to a base that has TTB aircraft assigned. A similar situation will exist for students selected for the FAR track. Figure 1 presents an graphic outline of the SUPT system's operation.

ATC is currently in the preliminary phase of acquiring an aircraft to fill the TTB role. This acquisition is expected to be an off-the-shelf multi-engine jet aircraft capable of conducting low-level navigation at 300 knots true airspeed. These new aircraft will be stationed at Columbus AFB, Vance AFB, and Reese AFB along with a contingent at Randolph AFB for instructor training. The TTB aircraft, designated the Tanker-Transport-Bomber Training System (TTBTS), will improve training for pilots selected for the TTB track by providing

phases: primary and basic. The primary phase is used to teach fundamental flying skills. Presently, the Cessna T-37 aircraft is used for this mission; however, it will be replaced by the Fairchild T-46 with an Initial Operational Capability (IOC) in 1987. The basic phase of UPT uses the Northrop T-38 aircraft to reinforce fundamental skills and develop additional flying skills required in operational aircraft. The UPT program also utilizes a variety of other instructional aids, including instrument flight simulators, cockpit procedural trainers, and classroom training.

The length of the current UPT program is 49 weeks. Seventeen training days are used for preflight training which consists of briefings, cockpit familiarization, study sessions, and general preparation for the primary phase. Currently, 81 days are used for primary phase and 108 days for the basic phase. Under SUPT, 105 training days will be required in each phase. The 105 days for primary phase will include 15 days for preflight. (In generalized UPT, preflight is separate from primary phase.)

Under the current program, eight classes enter UPT each year at six week intervals. The arrival date and the numerical class designation of each class is identical across all five bases. For example, class 85-01 is the designation of every class that arrives in November of 1983 and graduates as the first class of Fiscal Year (FY) 1985. A class starting primary phase enters one of six flights in the T-37 squadron and classes starting basic phase enter one of eight flights in the T-38 squadron. In the current program, two flights with approximately 35 students per flight enter training every six weeks.

Under SUPT, one flight with approximately 30 students per flight

1-6

Force Reserve, Air National Guard, and foreign countries. The pilots graduating from this program must be capable of qualifying in one of a variety of operational weapons systems in minimal time and at minimal cost. The increase in complexity of weapon systems throughout the Air Force, along with increasing training costs and approaching aircraft service lives, has required ATC to re-evaluate the structure of UPT. The goal of Specialized Undergraduate Pilot Training is to produce high quality, mission-oriented pilots in a cost-effective manner.

There are five UPT bases in the US: Laughlin AFB, Williams AFB, Vance AFB, Reese AFB, and Columbus AFB. Each year, forecasts are made to determine the number of pilots needed to fulfill Air Force requirements. Students are then selected and assigned to a specific base to attend pilot training. Each base can adequately train a limited number of students per year. These limitations are due to weather factors, the flying environment, number of aircraft, instructor pilot availability, and maintenance repair capability. Because of occasional changes in these factors, the capability of each base varies from year to year.

An important principal in the ATC training program is the idea of "smooth flow". Surges in the production rate at any given base are undesirable since there may be times when personnel and equipment are idle and other times when these resources are unduly taxed. Also, system surges have collateral effects. If a class transitions from one phase late, this may affect future transitions. This concept of smooth flow is even more important to the SUPT plan since the interactions between classes and bases are much more involved.

The structure of the current UPT program divides training into two

satisfy Air Force projected pilot training requirements. Based on the
results of this analysis, observations can be made regarding how
effectively the current program design is able to meet these
requirements. Additionally, the identification of those factors
contributing most to changes in the steady state operation of the system
will provide the Air Training Command with the necessary information to
assess the usefulness of the current program design.

Research Questions

To support the research objective, the following questions will be
investigated:

>   (a) What effect do changes in the levels of
>   certain factors within the SUPT program have on
>   the time required to complete each phase of
>   training at each UPT base? To satisfy the
>   research objective, one of these factors must be
>   the Air Force pilot production goal.
>
>   (b) Once the significant factors responsible for
>   the changes in the system have been identified, a
>   sensitivity analysis will be conducted to
>   determine how much variation within each factor
>   is possible before the factor causes a
>   significant change in the steady state operation
>   of the system.

System Definition

Having defined the problem and the research objectives, it is
important to understand how the system being studied actually operates.
It is this description of the system's operation that the analyst uses
to develop the conceptual design for the simulation model.

The Air Training Command is tasked to corJuct Undergraduate Pilot
Training for the US Air Force.   UPT also provides pilots for the Air

testing many of the variables associated with the development and implementation of this program. The objective in this analysis is to assess the ability of the current program design to satisfy Air Force pilot requirements. Since this concept of specialized, dual-track training has no recent precedent, it is important to determine which elements of the program have an impact on the amount of time required to complete the program and whether the current program design is capable of supporting Air Force pilot requirements.

Problem Statement

As mentioned in the previous paragraph, the proposed SUPT program is without recent precedent. The structure of this program is totally different from the current pilot training program, and bears little resemblance to the dual-track system previously used by the Air Training Command. Therefore, it is important that the Air Training Command develop new analysis techniques which are specifically oriented toward this new program. To contribute to the development of these new analysis tools, the first goal of this analysis is to produce a simulation model of the SUPT program operating in a steady state environment. After model verificatio. and validation, a second goal is to analyze what impact changes in specified levels within the model have on the time required to produce trained pilots and the ability of the current program design to satisfy Air Force pilot requirements.

Research Objective

The objective of this analysis is to determine which factors or combination of factors, during steady state operation of the Specialized UPT program, will significantly affect the ability of the program to

aircraft upon graduation, will participate in the Tanker-Transport-Bomber (TTB) flight training program. In this program, the students will accomplish their basic flight training in the new TTB trainer aircraft. This aircraft will be similar in performance to modern business jet transports.

The change from the current "single-track" pilot training program to the SUPT program is centered on the availability of a basic training aircraft. Due to its age and usage, the T-38 trainer is beginning to reach the end of its useful service life. The most cost-effective alternative to replacing the T-38 aircraft is restructuring the pilot training program. Several "independent studies" show that a specialized, dual-track flight training program "would be more cost-effective than the current UPT program." (13:1) With the introduction of the dual-track program, the T-38's useful service life can be extended, making it a viable FAR training aircraft "until beyond the year 2000." (3:47) In addition to delaying the costly appropriation of a new training aircraft, perhaps the most important outcome of the change to SUPT is the ability to provide a more realistic training environment for those student pilots destined to fly the larger aircraft in the Air Force inventory. Another outcome of the proposed change to the SUPT program will the amount of money the Air Force will save in fuel and operating costs. By procuring an "off-the-shelf" aircraft with more fuel-efficient engines and state of the art systems, the Air Force will realize a savings of a nearly "50,000 dollars per TTB graduate, which translates into a significant 55 million dollars per year savings in our pilot training program" (3:47)

To date, the Air Training Command (ATC) has been analyzing and

wrote to the Chief of Staff of the Air Force:

> "The superior speed and performance of the T-37 will be such that subsequent basic training in B-25 aircraft will be an illogical training progression." [7:1-2]

General Myers advocated that all student pilots should be trained in jet aircraft because: (a) most of the Air Force inventory was composed of jet aircraft; (b) it was much easier to transition from a jet aircraft to a piston-powered aircraft; and (c) such a program would cost less and provide a "universally assignable" product. (1:13-14)

On January 28, 1959, the Air Force graduated its last students from the basic multi-engined training program and retired the B-25. From this date until the present, undergraduate pilot training has been conducted as a single-track, all jet program. (1:14-15) In the twenty one years between the phase-out of the specialized dual-track training system and its revival in 1980, the Air Force conducted several surveys and analyses to confirm the adequacy of the generalized training program. Throughout the 1960's, studies indicated that producing a universally assignable pilot did meet Air Force requirements. However, these studies also confirmed that, based solely on pilot production rates, the T-38 and T-37 aircraft would have to be retired around the middle of the 1970's. As the pilot production rates increased in response to the Vietnam conflict, the airframe retirement dates for each of these aircraft continued to move closer to the present.

In assessing a need for new airframes, the Air Training Command accepted the concept of total program analysis. Under this concept, the Air Force and ATC assessed the impact of the replacement of training

aircraft on the entire training program. In the early studies comprising this analysis, the concept of generalized UPT was continually supported. The recommended means of extending the service life of the T-38 and T-37 was the increased utilization of simulators in the UPT curriculum. However, these same studies supported the concept that a specialized pilot training program was a cost-effective method of training. (14:4-7) The recommendation for the use of simulation did result in ATC acquiring more simulators. This action, coupled with the de-escalation after the Vietnam conflict, caused the service life of both training aircraft to be extended beyond the dates previously determined. This fact relegated the need for replacement aircraft, for the moment, to the realm of future plans.

On the subject of specialized UPT, the Air Force elected to continue to study the concept. Two factors contributed to this decision. First, with the concurrent development of such advanced weapons systems such as the F-15, A-10, and the B-1, the Air Force did not have the funds to procure a new Tanker-Transport-Bomber (TTB) trainer aircraft. Secondly, senior Air Force officers expressed concern that the lack of a universally assignable UPT graduate would greatly degrade the assignment flexibility of pilots. Based on their recent Vietnam experiences, the senior staff members were concerned that specialized UPT could not adequately respond to a need for a particular type of pilot (i.e. could not produce enough fighter pilots and could not retrain TTB specific pilots). These two factors, combined with the extended service life of the airframes delayed the consideration of SUPT. This delay, however, was short lived.

In 1977, in a move to recover from an airline pilot hiring boom and

the Vietnam draw-down, pilot production rates rose to 1,000 per year and were projected to continue to rise to a level of 2,200 by 1985. This rapid increase in pilot production greatly reduced the expected service life of the T-38. By this time the Air Force had funded a separate acquisition program for the Next-Generation-Trainer (NGT) to replace the T-37. Suddenly, the Air Force was faced with the choice of requesting funding for a new supersonic trainer or adopt the specialized UPT program. Again, two factors contributed to the acceptance of the SUPT concept. First, the Congress had tied the Defense Department to a plan to increase inter-service utilization of specified systems. To procure a new supersonic trainer, the Air Force would have to become a partner in an existing Navy trainer acquisition program. The cost of this joint program was excessive when compared to the cost of implementing SUPT. The second factor contributing to the acceptance of SUPT was that ATC had convinced the senior Air Force officers that the specialized program could respond to demands for a particular type of pilot and that the program represented a considerable cost savings. Based on these factors, the Air Force formally accepted the concept of specialized UPT program and began taking the steps necessary to implement such a program. (3:46-47)

It is evident from this brief historical review that the concept of a specialized pilot training program was not conceived in haste. Rather, it has been studied and analyzed since the Air Force chose to adopt an all-jet single-track pilot training concept. To provide an insight into how to conduct this analysis of the SUPT program, it is important to understand the nature of the studies applied to the specialized pilot training concept in the past.

2-6

Related Studies

Since the adoption of a single-track training program, the Air Force has consistently evaluated this program to insure it is capable of meeting its pilot training needs. In almost every study, the concept of a specialized program was considered as the alternative to the current program. Although the specialized program was found to be a cost-effective concept, it did not appear to satisfy the Air Force need for a universally assignable pilot. The majority of the studies and research reports conducted on the specialized pilot training program assessed the impact of not producing a universally assignable pilot on the flexibility of Air Force pilot assignment policies both in peacetime and war. As mentioned before, it was not until senior Air Force officers were convinced that the specialized program would have no adverse effect on pilot assignability that the specialized pilot training concept was approved.

Unfortunately, this study is not focused on the personnel aspect of the specialized training program. Rather, it seeks to determine whether or not the current program design will satisfy Air Force requirements. In the recent past there have been two studies conducted whose main goal was analyzing pilot training implementation plans.

The first of these studies was conducted by Major Seth Jensen while a student at the Air Force Institute of Technology. Major Jensen's study attempted to analyze the implementation plan developed by ATC to convert from the T-37 primary training aircraft to the new T-46 aircraft. Using data taken from the T-46 Master Implementation Plan, an ATC document outlining the actions necessary to initiate a smooth transition from one aircraft to the other, Major Jensen used a hand

2-7

calculator to verify ATC calculations and assessments. His conclusion was that the program, as outlined by the implementation plan, could not satisfy Air Force training requirements. Due to his use of a hand calculator, Major Jensen limited his ability to conduct a thorough analysis of all factors in the program. In addition, his use of mean or average data values did not allow him to account for the variance in some factors or the stochastic nature of some of the variables.(4:20-21)

In an attempt to resolve the inadequacies of Major Jensen's study, a second study was conducted by students at the Air Force Institute of Technology. Major Jack Dickinson and Captain Glenn Moses developed a simulation-based analysis of the T-46 implementation program at Laughlin AFB.(4) By using simulation as the vehicle for conducting their analysis, Major Dickinson and Captain Moses were able to deal with the random nature of some of the variables involved in the implementation program. In addition, they were able to conduct a rigorous screening procedure to determine the factors critical to the successful accomplishment of the aircraft changeover. The success of this study in providing ATC planners with a tool for analyzing the T-46 implementation program is what initiated the development of this analysis of the specialized undergraduate pilot training program.

The Automated Training Capability Model (15)

A review of the techniques and programs used to analyze UPT would not be complete without discussing the current model used by ATC planners to evaluate UPT program design capability. Developed as a means of alleviating the tedium of hand calculations, the Automated Training Capability Model is used to predict "the maximum pilot training capability at each <pilot training> wing under specified conditions."(4:18) To provide this information, the model conducts two separate operations. In the first operation, the model uses equations to determine each wing's sortie generation capability. This factor is a function of runway availability, aircraft and instructor availability, number of daylight hours per training day, maintenance abort rate, and weather cancel rate. After arriving at the unit's sortie generation capability, daily flying training is simulated to determine "the largest constant student load that can be sustained utilizing <the unit's calculated generated sortie capability>."(4:19) An important detail about the operation of the model is that data for weather and maintenance aborts, student attrition and other stochastic variables is presented in an average or mean-value form. For example, weather cancel rates for primary training are determined by taking the average of weather cancel rate data for the past several years. Although this is less time consuming than using a distribution to represent the stochastic data, its use does not allow ATC planners to account for the variance that is common in many of these natural phenomenon. This model is capable of providing ATC planners with the following information: "(a) Factors for distributing an equitable workload to each wing, (b) The impact of major program changes, (c) The best location for new

2-9

training programs, and (d) An assessment of base requirements during periods of expanding or declining pilot production." (4:18)

Although the Automated Training Capability Model cannot account for the random nature of some of the variables operating in the pilot training environment, it does give the ATC planners an automated tool for making their assessments. In addition, it possesses a large data base from which information can be drawn to initiate other studies. It is this capability which was used rather extensively in the conduct of this analysis.

System Operational Concept for the Tanker-Transport-Bomber Training System. (SOC) (13)

Prepared by the ATC Deputy Chief of Staff for Plans, this document is essentially the blueprint for the specialized undergraduate pilot training program. Its purpose is to "describe the concept of operations for <the> Tanker-Transport-Bomber Training System (TTBTS)." (13:1) The TTBTS is the sub-program within the SUPT program structure which sets SUPT apart from the generalized training program currently in use. The main contribution of the SOC to this analysis was its description of the SUPT program. Since this program does not yet exist, the SOC was invaluable in providing the analysts with a clear outline of how the system should operate in a steady-state environment. Aside from presenting the general concept of the TTBTS, the SOC also outlines the training standards to be used in the program, the training aircraft performance requirements, required instructor pilot manning, and logistics and maintenance support requirements.

Summary

Before designing and implementing an analysis, it is a prudent step to thoroughly review the subject to be analyzed. In this section, a brief historical review of the undergraduate pilot training program showed that the subject of specialized pilot training has been an integral part of many analyses. However, few of these analyses address the implementation of such a program. Rather, they are concerned with how to structure the program and what effect the adoption of such a program will have on the assignability of its graduates.

Of those analyses which did study the implementation of a pilot training program, the study by Major Dickinson and Captain Moses served as an outline for the design of this study. The capability of addressing the variance in many of the factors in the pilot training process is an important instrument which ATC does not currently possess. In this vein, the principal analysis tool currently used at ATC, the Automated Training Capability Model, was discussed. It's main contribution to this analysis was the data compiled in its extensive data base. Much of this data was used to develop and validate the steady-state operation of the model in this analysis.

Lastly, the overall outline for the operation of the SUPT program, the Statement of Operational Capability (SOC) was reviewed. Since the SUPT program is still in the planning stage, the SOC served as a blueprint for the operation of SUPT.

III. Model Formulation

Conceptual Model

To conduct a proper analysis of the SUPT program it is imperative the simulation model accurately reflects the actual operation of the system. With this goal in mind, the conceptual model of the system represents the entire SUPT system in a steady-state condition, meaning that SUPT is considered fully implemented and in its day-to-day mode of operation.

The model begins with the initialization of many of the variables necessary to place the system in a steady-state environment. In addition, those variables which remain constant throughout the entire operation of the system are also initialized. These variables include:

> (a) The percentage of students completing primary training that are sent to FAR training versus TTB training.
>
> (b) The number of days required to accomplish a PCS move if the student must move to another base to complete his training.
>
> (c) The number of students that enter primary, FAR and TTB for each class at each UPT base.
>
> (d) The number of aircraft, simulators, and instructor pilots assigned at each UPT base.

The percentage of students sent to FAR is a constant percentage established by ATC. The current plan calls for 40 percent of the primary phase students to proceed to the FAR track. The remaining 60 percent of the primary students will proceed to the TTB track. This particular variable is one which raises many questions in the minds of Air Force senior staff planners. The specific area of concern is ATC's

3-1

ability to produce FAR trained pilots in the event of a war. Air Training Command claims that the 40 percent figure for FAR is the absolute maximum percentage of students that can be trained in FAR. The restriction is due to the number of T-38 aircraft available and the design of the syllabus for the FAR program. Therefore, one of the subjects of this analysis will be to determine if indeed the 40 percent figure is the maximum feasible fraction and what effect an increase in the fraction will have on the ability of the program to produce the required number of pilots.

In the event a student is selected for a program that is not available at his primary training base, the maximum amount of time allowed for a PCS is the length of time between class start times. Current ATC plans establish 15 days as the maximum number of days allocated for a PCS move. For the purposes of this model, all times are expressed in working days. Therefore, in three weeks there are 15 working days.

The size of each entering class in each phase of training at each base is based on several factors. These factors include:

> (a) The Air Force pilot production goal. The goal used for this model is ATC's projected pilot production goal for SUPT, 1910 pilots per fiscal year.

> (b) The percentage of the total class load assigned to each UPT base. As mentioned earlier, each base is allocated a certain percentage of the overall class load based on assigned assests, (i.e. aircraft, simulators, and instructor pilots), area weather, and a review of the base's historical pilot production rate. Table I lists the percentages of the overall load allocated to each base, for each phase, currently used by ATC Directorate of Operations Plans (DOX) personnel. For FAR and TTB, the percentages listed are of

the 40 and 60 percent of the total primary graduates who proceed to the basic phase.

(c)   The total number of days in a year during which training can be accomplished. According to ATC planners, there are 105 scheduled training days in each phase. However, in each of the phases of training, there are 123 working days during which training can be accomplished. The additional working days have no training scheduled and are used as necessary. Therefore, the total number of days available for training in a year is 246. This figure excludes federal holidays, weekends, and Christmas break.

(d)   Final percentage of students expected to successfully complete the entire phase of training. For the primary class levels, the overall attrition rate is figured using the primary and basic attrition rates. Since there is no data on attrition for primary training using the T-46, the average primary attrition rate for the current training program was used. For the basic attrition, the average attrition rate for the current basic phase was used. To compute the basic class levels, the attrition rate used was the average basic attrition rate.

Table I

Student Load Allocation

Laughlin Primary ---- 21.0 percent
Laughlin FAR -------- 48.7 percent
Williams Primary ---- 22.1 percent
Williams FAR -------- 51.3 percent
Reese Primary ------- 18.0 percent
Reese TTB ----------- 31.6 percent
Vance Primary ------- 18.9 percent
Vance TTB ----------- 33.2 percent
Columbus Primary ---- 20.0 percent
Columbus TTB -------- 35.2 percent

The following equation is used to compute the class size at each base using the variables listed above.

$$\text{Class Size} = \text{GOAL} \times \frac{(\text{DAYS/CLASS ENTRY})(\% \text{ OF LOAD})}{(\text{DAYS/YEAR})(1-\text{ATTRITION RATE})}$$

Using this equation, class loads were computed for the 40/60 percent FAR/TTB mix and a overall goal of 1,910 graduates per year. Table II lists the results of these calculations in the form of class load per base.

The remaining factors remain constant throughout system operation. These factors include the number of aircraft assigned to each base for each phase of training, the number of simulators assigned at each base, and the number of instructor pilots assigned.

The number of aircraft assigned at each base for each phase of training is taken from the Automated Training Capability Model. One of the outputs of this model is a listing of all the assets assigned at each UPT base including the total number of T-46's, T-38's and TTB aircraft. To more accurately define the number of aircraft actually available for training, the output also lists the aircraft ready-rate and the percentage of the time runways are available for use by students. From these three values, the number of aircraft available for training is computed by multiplying the total number of assigned aircraft by the ready rate and the student use rate. Table III lists the results of this calculation.

Table II

Class Loads Per Base

Laughlin Primary ----- 30 students
Laughlin FAR --------- 24 students
Williams Primary ----- 31 students
Williams FAR --------- 25 students
Reese Primary -------- 26 students
Reese TTB ------------ 23 students
Vance Primary -------- 27 students
Vance TTB ------------ 25 students
Columbus Primary ----- 29 students
Columbus TTB --------- 26 students

In the model, the number of TTB aircraft allocated for training is doubled to account for the fact that two students are trained per flying sortie. This is a departure from the single student-single instructor-single aircraft system currently in use.

According to ATC/DOX personnel and data taken from the Automated Training Capability Model, each base has two simulator complexes, one for each phase of training. Within each of these complexes, there are eight simulators. In the model, the number of simulators at the TTB bases is doubled to account for the fact that two students are trained in each simulator session as opposed to the standard one student per session found in the primary and FAR phases of training.

Table III

Aircraft Allocated To Training

Laughlin's T-46's ------------ 55 aircraft
Laughlin's T-38's ------------ 61 aircraft
Williams' T-46's ------------ 55 aircraft
Williams' T-38's ------------ 62 aircraft
Reese's T-46's -------------- 53 aircraft
Reese's TTB's --------------- 51 aircraft
Vance's T-46's -------------- 49 aircraft
Vance's TTB's --------------- 51 aircraft
Columbus' T-46's ------------ 54 aircraft
Columbus' TTB's ------------- 51 aircraft

The number of instructor pilots assigned to each base for each phase of training is based on the programmed yearly student production load. In addition to assigned instructor pilots, certain members of the wing staff serve as "guest" instructors from time to time. In the implementation of this model, these guest instructors were included in the overall instructor pilot complement. For each phase of training the following equations were used to compute the number of instructors:

For Primary Phase (T-46): $(88 + .1924(X)) + ($"Guest" Instructors$)$

For Basic Phase (FAR): $(85 + .2667(X)) + ($"Guest" Instructors$)$

For Basic Phase (TTB): $(76 + .2384(X)) + ($"Guest" Instructors$)$

Using these equations, the total instructor pilot complements for each base and training phase are listed in Table IV.

Continuing with the algorithm used to compute TTB aircraft and simulator availability, the number of instructors for the TTB phase of training used in the model is double the calculated figure. This accounts for the fact that during flying sorties and simulator sessions, one instructor will be training two students.

Table IV

Total Instructor Pilot Complement

```
Laughlin Primary --------- 160 instructors
Laughlin FAR ------------ 172 instructors
Williams Primary --------- 162 instructors
Williams FAR ------------ 182 instructors
Reese Primary ----------- 164 instructors
Reese TTB --------------- 167 instructors
Vance Primary ----------- 164 instructors
Vance TTB --------------- 153 instructors
Columbus Primary --------- 165 instructors
Columbus TTB ------------ 167 instructors
```

Table VI

Results of Kolmogorov-Smirnov Goodness-of-Fit Test

Distribution	Mean	Std Dev	D max	D,a=.01
T-37 Attrition	13.773	3.92164	.173	.257
T-38 Attrition	5.2533	1.85967	.131	.257
T-37 Mnx Abort	2.5576	0.51053	.134	.179
T-38 Mnx Abort	3.0909	0.31658	.153	.179
Weather Cancel Rate Data				
Laughlin T37 Wnt	28.587	9.01577	.153	.257
Laughlin T37 Spg	22.560	13.0198	.185	.257
Laughlin T37 Sum	13.387	6.27863	.162	.257
Laughlin T37 Fal	18.147	6.96223	.096	.257
Laughlin T38 Wnt	26.813	8.77129	.139	.257
Laughlin T38 Spg	24.460	9.98898	.113	.257
Laughlin T38 Sum	15.560	5.36427	.155	.257
Laughlin T38 Fal	20.380	7.78734	.177	.257
Williams T37 Wnt	12.793	7.34048	.162	.257
Williams T37 Spg	6.8533	5.14016	.132	.257
Williams T37 Sum	6.9600	3.82058	.116	.257
Williams T37 Fal	5.0133	5.84831	.210	.257
Williams T38 Wnt	14.313	8.75123	.120	.257
Williams T38 Spg	5.5067	3.00083	.147	.257
Williams T38 Sum	9.4267	3.97465	.245	.257
Williams T38 Fal	6.3400	5.81965	.214	.257
Reese T37 Wnt	33.740	8.21582	.121	.257
Reese T37 Spg	27.373	10.0298	.105	.257
Reese T37 Sum	13.647	7.70713	.122	.257
Reese T37 Fal	26.733	12.2182	.165	.257
Reese T38 Wnt	31.793	9.08354	.123	.257
Reese T38 Spg	27.500	10.1188	.124	.257
Reese T38 Sum	16.613	7.69080	.114	.257
Reese T38 Fal	24.693	10.8673	.159	.257

considered more valid and more powerful. Unfortunately, the standard K-S test is not valid when parameters have been estimated from the data. The null hypothesis for this test is that the real underlying distribution in the data equals the hypothesized distribution. It has been found that the standard K-S test has a lower probability of a TYPE I error, that of rejecting the null hypothesis when it is true, when parameters have been estimated from the data. The problem arises from the fact that by using parameters estimated from the data, the power of the test is reduced. It is the power of the test which is most important when the null hypothesis is as stated above, since it controls the risk of accepting an invalid distribution. Lilliefors (8) generated a modified table of critical values for the K-S test for use when a normal distribution is hypothesized and parameters are estimated from the data. The table was created based on the results of thousands of Monte Carlo simulations. By performing an analysis of the data from these simulations, he found that the power of the test using the modified table was correct when parameters were estimated.

The parameters derived for each of the empirical distributions, the mean and the variance, were used in conjunction with Lilliefors' modified table to determine whether the historical data did indeed represent a normal distribution. The results of the tests on the historical data are compiled in Table VI.

To reject the null hypothesis that the empirical data distribution is a normal distribution the computed D_{max} must be greater than the D test statistic found on the modified table for a particular level of significance. As can been seen from the table, all the data conform to a normal distribution at a level of significance of 0.01.

3-19
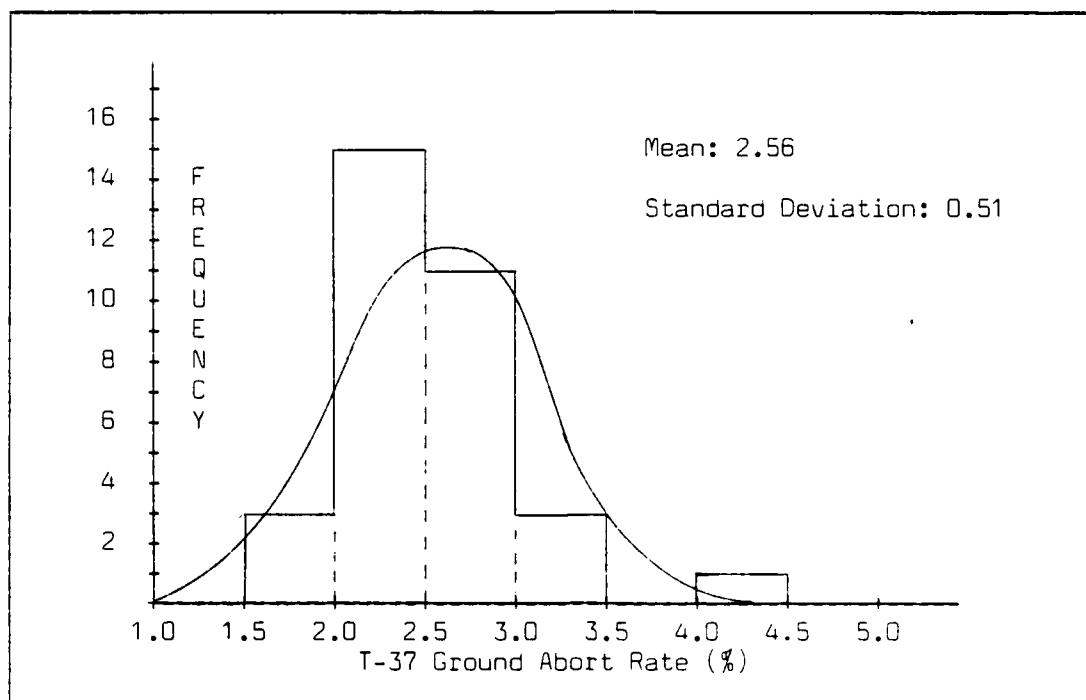
Figure 6. T-37 Maintenance Ground Abort Rate
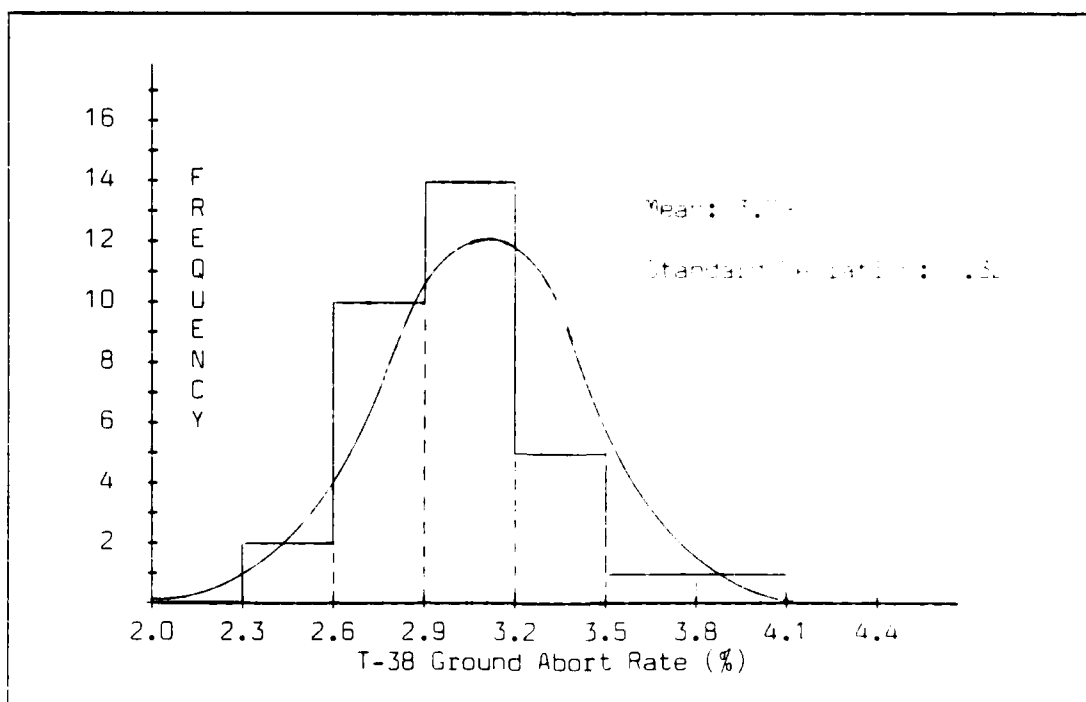
Figure 7. T-38 Maintenance Ground Abort Rate
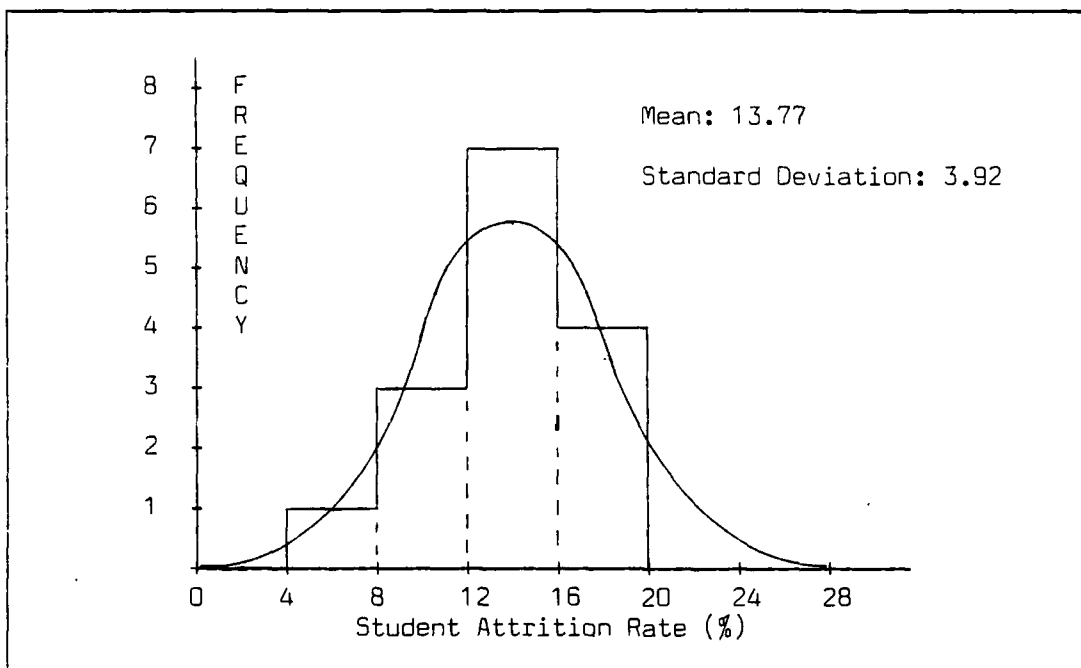
Figure 4.   Primary Phase Student Attrition Rate
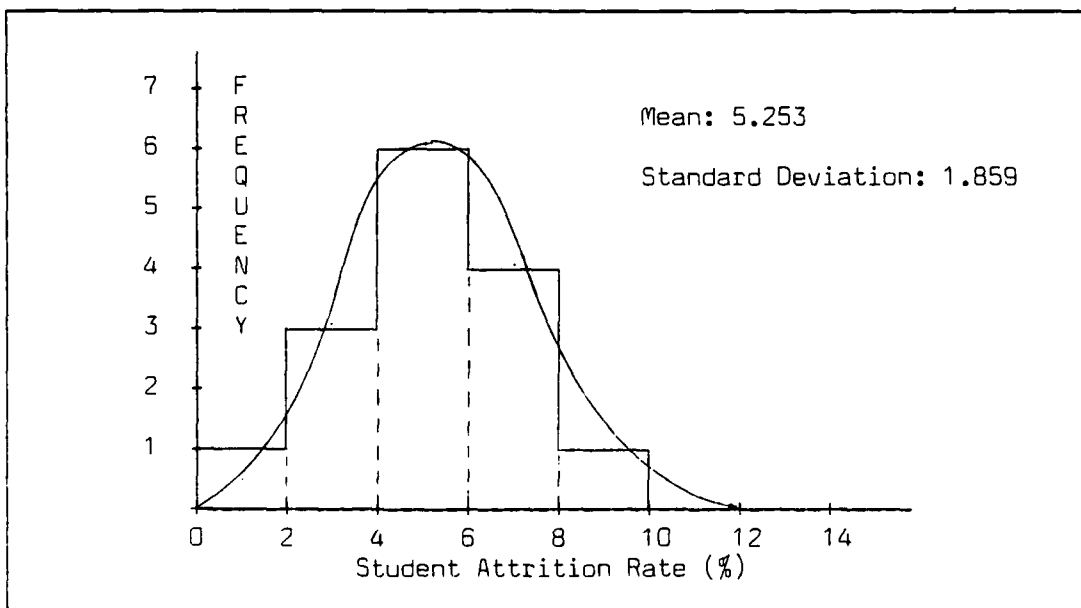
Figure 5.   Basic Phase Student Attrition Rate

tors were integrated into the entire training process. The use of these full motion, complex simulators reduced the number of instrument flight sorties required and therefore reduced the number of sorties which were allowed to fly in other than VFR conditions. The maintenance ground abort rate only spans three years because this was the only data available that was readily accessible to ATC personnel. Lastly, student attrition spans the last 15 years because of the nature of the current generalized UPT system. The syllabus changes in the current program have not been that significant to warrant reducing the sample size to the last few years. This point can be argued several different ways, but the crucial point in this case is that student attrition is affected by a myriad of policies and changes. Since it is impossible to isolate any one of these factors as the causal factor, it seems the prudent decision to use as many samples as possible.

After gathering the data, it was plotted to determine what theoretical distribution would most likely fit the data. The normal distribution appeared to adequately fit the empirical data. As examples, histograms for the distributions of student attrition and maintenance ground aborts are presented in Figures 4 through 7. Based on the assumption of normality, the distribution parameters, the mean and the variance, were computed.

To verify the assertions of normality of the data, the Kolmogorov-Smirnov (K-S) Goodness of Fit test was used. An alternative non-parametric test, the Chi-Square test, was considered. However, due to the small sample sizes involved, the Kolmogorov-Smirnov test was

the areas of number of daylight hours per training day, number of
aircraft assigned per base, the distribution of student attrition over
the course of a training phase, runway usage, sortie turnaround times,
number of flying sorties and simulator sorties required per training
phase, sortie refly factor, and total number of training days per fiscal
year. Since the values used in this model are what ATC reasonably
expects to occur, many of the constants used in this analysis are drawn
from the data provided by the Automated Training Capability Model.

The areas which lend the most variation to the outcome of the model
are the weather cancel rates, the maintenance abort rates, and the
student attrition rates. To adequately deal with these factors, mean
values are not sufficient. To model the "real world" aspects of these
activities, random draws from a probability distribution must be used.
This is why a simulation model of SUPT was designed for this analysis as
opposed to a more traditional deterministic model.

The first step in determining the probability distributions of each
of these factors was to gather historical data. The Office of Histor-
ical Research at ATC has compiled records of all this information which
extends in some cases back to the Second World War and earlier. To keep
the data collected as current as possible and still obtain a reasonable
sample, historical data was gathered for the past five years in the
case of weather cancel rates, for the past three years for maintenance
ground abort rates, and for the past 15 years for the student attrition
rates. At this point an explanation is warranted concerning the number
of years of data collected. The reason weather aborts were only tracked
for the past five years results from a change in the course syllabus in
the 1979 - 1980 time frame. At this time, the Instrument Flight Simula-

is limited to accomplishing one training activity per training day if that activity is a flying sortie. Otherwise, the model logic remains the same. At the end of the basic training phase, statistics are collected at each base to determine the time required for each student to complete the entire SUPT training program. As with the statistics collected in the primary phase, these values are collected over time, thereby providing a mean time to complete the program and a count of the number of students completing the program in a specified time.

Data Collection

The data used in this model is drawn from three sources: interviews with personnel assigned to the Directorate of Operations Plans, Headquarters Air Training Command; the Automated Training Capability Model currently in use at Air Training Command; and historical data obtained from the Office of Historical Research, Headquarters Air Training Command.

The interviews with ATC/DOX personnel provided insight into the functioning of the SUPT system. Information concerning the number of instructor pilots assigned to each base, the number of aircraft allocated for training at each base, and the percentage of the student training load allocated to each base are examples of the types of data gathered from these interviews. As mentioned in the previous chapter, the Automated Training Capability Model is an analytical tool used by ATC. Written in COBOL, it is designed to provide information on the operation of the SUPT program based on mean values as inputs to the system. It is not capable of accounting for the variance which occurs within factors in the system. However, it is a good source of data in

flying abilities, and the student's wishes. In the model, a probabilistic branching is used to direct approximately 40 percent of the students to the FAR phase and 60 percent to the TTB phase.

After being placed in their respective advanced training phases, the students enter the assignment algorithm. Within this algorithm, the model determines to which training base the student will be assigned to complete basic training. The algorithm works on the premise that if a training slot is available at the student's primary base and he has been selected for that type of training then he will remain at that base for the remainder of his training. However, if the student's primary base does not offer the advanced training required or there are no training slots available, the algorithm will send the student PCS to another base. The logic within the algorithm attempts to model concepts used by the Air Force assignment process by trying to assign those persons requiring a PCS to bases in close proximity to the primary training base. However, the algorithm also attempts to establish a balance between all the bases. In so doing, it may, at times, assign a person to a base not in close proximity to his current training location. Regardless of the proximity of the new training base, if the student is sent PCS, he is allowed three weeks (15 training days) to accomplish that move.

Upon arriving at the basic training base, the student draws another overall attrition rate for this phase of training. The remaining processes are very similar to the ones described above for primary training. Perhaps the only difference in this portion of the model is that in the TTB phase, the flying sortie length is longer than the sorties flown in the primary and FAR phases. Consequently, the student

3-13

flying sortie, the flying sortie count is incremented and stored as a student attribute. The aircraft is then released and the student is debriefed by the instructor pilot. The length of this debriefing is designed to insure the instructor pilot completes one of his three activities per day. Once the debrief is completed, the instructor pilot is released. At this point the model determines whether or not to eliminate the student from the program. This is accomplished by a FORTRAN insert which uses the overall attrition rate drawn by the student upon his entry to the training phase and the flying sortie count. If not eliminated, the student is delayed for the balance of one-half of a training day before returning to the node which assesses his remaining training requirements. However, if eliminated, the student is removed from the system.

Upon completion of all the training requirements for the primary phase the model collects statistics on how long the student spent in this particular phase of training. Since this collection process is cumulative, it provides the analyst with a mean time spent in the phase and a count of how many students completed the phase during a specified time period. Any student completing his training requirements before the scheduled completion date for his flight is delayed until that date is reached in the model. This agrees with the routine currently used in UPT. Students completing their training requirements after the scheduled completion date are recorded as being late. Once these statistics are collected, the student meets the Advanced Training Recommendation Board (ATRB). In reality, this board is convened to determine the type of advanced training each student will receive (i.e. FAR or TTB). This determination is based on the needs of the Air Force, the student's

delayed the length of one training period, one-third of a day, and returns to the node which assesses his remaining training requirements.

In the event of favorable weather, an aircraft and an instructor pilot resource are assigned to the student. The next probabilistic event is drawing a maintenance abort rate. Again, as with the weather cancel rate, this rate is drawn from a distribution of maintenance ground abort rates for each aircraft type. If the student encounters a maintenance abort, the aircraft is released to maintenance for repairs and an attempt is made to assign a spare aircraft. If no aircraft resources are available, the instructor pilot is released and the student waits for the next training period to commence (i.e. the student is delayed for one-third of a training day). When the aircraft is turned over to maintenance, the model assumes that only minor repairs are required. Therefore, the release of the aircraft resource is delayed for approximately one and one-half hours to simulate maintenance down time.

Assuming the student does not encounter a maintenance abort, the flying training sortie is completed. The length of each type of sortie, (primary, FAR, and TTB) is computed from information provided in the Automated Training Capability Model. This model provides an aircraft turnaround time as one of its data outputs. This turnaround time is a measure of the time elapsed from the initiation of one flying sortie to the initiation of another sortie. Using this time and the average number of daylight hours per training day, (ATC normally conducts training only under Visual Flight Rules (VFR) conditions and usually only during daylight hours), the flying sortie durations are computed to be: 0.22 (2.75/12.67) days per sortie for primary and FAR and 0.36 (4.6/12.67) days per sortie for TTB. Once the student completes the

3-11

Perhaps, for the sake of clarity, it is necessary at this point to digress from the flow of the model for a moment and discuss the scheduling heuristics employed in this model. As mentioned in the preceeding paragraph, each student is allowed to accomplish two training activities per day. This is the normal operating procedure in pilot training. However, in the event the student or a group of students should fall behind in the training program, then training might be accelerated. Since this analysis seeks to determine the ability of the program to successfully satisfy Air Force requirements, it employs a "worst-case" scenario and assumes that there will be no need to deviate from the established training policy. Each instructor pilot can accomplish three activities per day in the model. This structure coincides with the algorithm used in allocating simulator and flying sorties and is the standard procedure used in UPT.

Returning to the flow of the simulation model, it is evident that one of the most complex activities in this program is the flying sortie. Its complexity results from several probabilistic events which contribute to its success or failure. After determining that the student requires flying training and that sufficient resources are available to accomplish that training, the model draws a weather cancel rate from the distribution of weather cancel rates for that specific base and phase of training. (The determination of the weather cancel rate distributions will be addressed later in this chapter.) If the student draws a weather cancellation, the program checks to see if simulator training is required and whether or not a simulator is available. If the answer to both of these questions is "Yes," the student is scheduled for a simulator session. Otherwise, the student is

3-10

The number of simulator sessions and flying sorties required were drawn from the proposed SUPT syllabus in the System Operational Concept document. The flying sortie requirement was multiplied by a "refly factor" provided by ATC/DOX which accounts for the expected number of sorties that will have to be reaccomplished due to poor student performance, equipment problems, etc. Table V lists the sortie and simulator requirements for each phase of training.

Based on syllabus requirements and availability of resources (aircraft, instructor pilots, and simulators), the students are either scheduled for a simulator session or a flying sortie. If the student draws a simulator session, one half of a training day is allocated for accomplishing this activity. The actual simulator session lasts about three hours including debriefing, but the model limits students to the established ATC normal daily training load of two training activities per training day. By making the student use one-half of a day for the simulator activity the model insures adherence to this policy. Upon completion of the simulator session, the student's simulator completed count is incremented and stored as a student attribute. After the half-day period is over, the student returns to the node which assesses remaining training requirements. Again, based on student needs and available resources, training is scheduled.

Table V

Phase Training Requirements

	Sorties	Sims
Primary	68	27
FAR	89	27
TTB	61	27
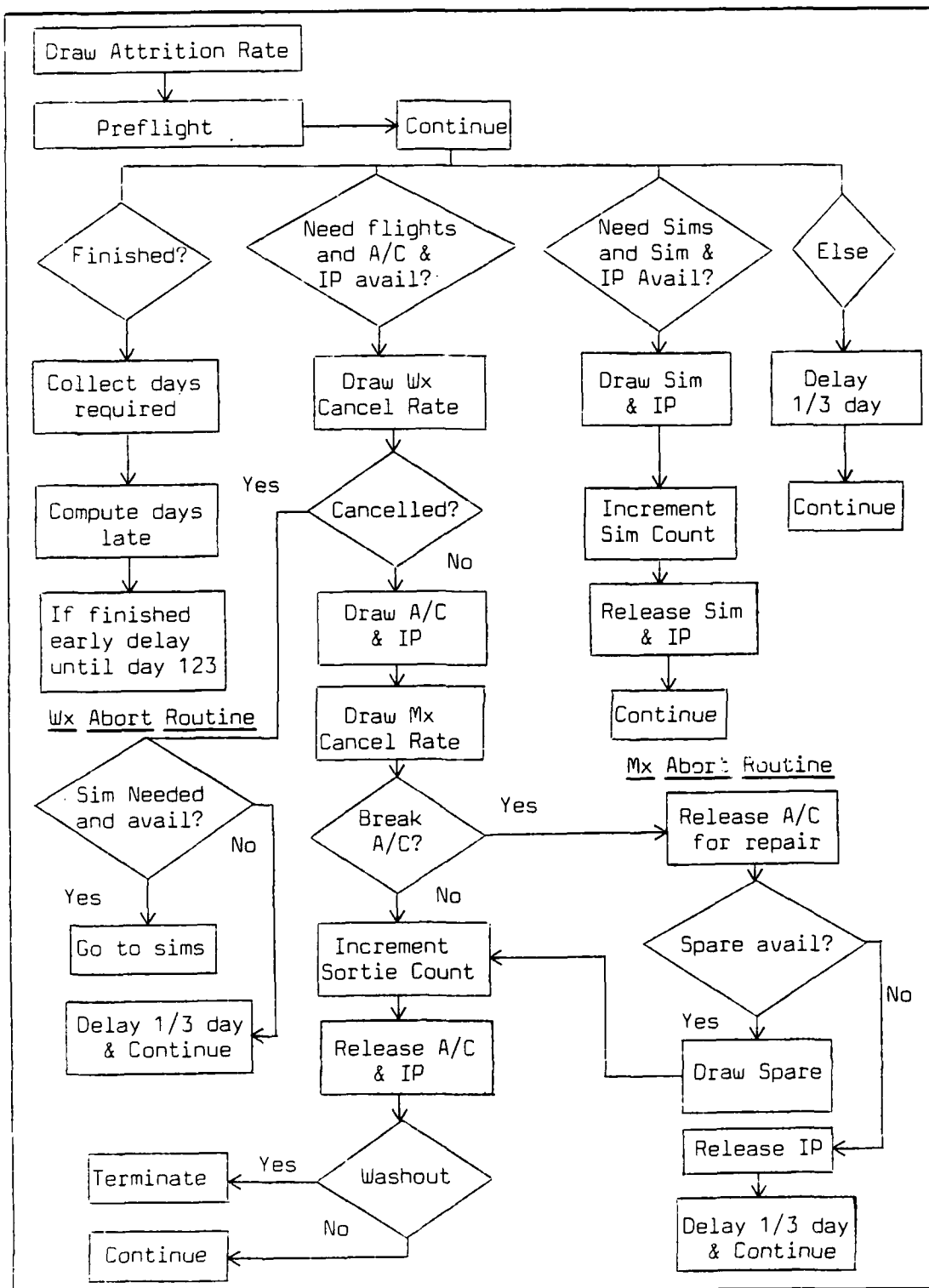
Figure 3. Phase Logic Flow

Mathematical Model

In the following discussion of the program's operation, the reader may refer to Figure 3 and the source code listing in Appendix C. Once the model is initialized, it begins processing in the SLAM network. The first step is to build the entering classes. During this process, each student is assigned an attribute noting his class number and an attribute indicating the day he started primary training. After the proper number of students are allocated to a class given the variables described above, the students proceed to their assigned primary bases. The first activity each student accomplishes is drawing an overall attrition rate for the phase of training. At various points in each student's progress through a phase, this attrition rate is used to compute the probability of being eliminated at that particular time. Thus, the attrition of students is spread throughout the program.

After drawing an attrition rate, the student accomplishes the first activity of the primary phase, pre-flight familiarization training. At this point in the model, the program also accounts for the days each student spends in academics throughout the primary phase. The number of days allocated to academics is 22, which is equal to 20 percent (two hours of a typical ten hour duty day) of the remaining 108 days in primary phase. After completing this activity, the program determines the remaining training requirements of each student.

3-7

Table VI (Contd)

Results of Kolmogorov-Smirnov Goodness-of-Fit Test

Distribution	Mean	Std Dev	D max	D,a=.01
Weather Cancel Rate Data				
Vance T37 Wnt	29.967	11.9040	.159	.257
Vance T37 Spg	22.280	6.92565	.154	.257
Vance T37 Sum	9.9800	5.17773	.137	.257
Vance T37 Fal	20.413	7.71213	.133	.257
Vance T38 Wnt	31.900	14.3304	.178	.257
Vance T38 Spg	24.580	7.46996	.176	.257
Vance T38 Sum	12.233	6.95800	.094	.257
Vance T38 Fal	21.753	9.03097	.162	.257
Columbus T37 Wnt	30.440	8.72777	.149	.257
Columbus T37 Spg	24.026	6.46457	.137	.257
Columbus T37 Sum	23.333	10.0207	.176	.257
Columbus T37 Fal	22.220	6.55299	.234	.257
Columbus T38 Wnt	30.013	11.7361	.121	.257
Columbus T38 Spg	22.313	6.85908	.187	.257
Columbus T38 Sum	22.260	8.38160	.117	.257
Columbus T38 Fal	21.807	5.36543	.137	.257

Based on these results, the student attrition, weather cancel rates, and maintenance abort rates are drawn from normal distributions with the parameters listed in the table. At this point it must be noted that in reality the T-46 weather and maintenance rates are T-37 data and the T-38 and the TTB aircraft share the same weather and maintenance data. This approach was taken based on the similarity of the aircraft and the lack of data on the new aircraft. This was also the approach recommended by ATC.

Model Translation

Using the relationships described in the previous section, a SLAM network simulation was constructed. As mentioned earlier, Appendix C contains a complete listing of the SLAM Code. To streamline the program as well as make the program more understandable, the code used to draw the weather abort rates, the overall student attrition rate, and the maintenance abort rate, was written as part of a FORTRAN program. This program was also used to compute the actual student attrition throughout the course of the model run. For a full listing of the FORTRAN program, see Appendix D.

Verification

Verification is the process of insuring that the simulation program performs as the designer intends. The ultimate purpose of verification is to ensure the conceptual model is accurately reflected in the computer code (2:379). The process of eliminating features of a program which cause it not to behave as desired is commonly called debugging. With a complex model like the one in this analysis, this verification process can be very time consuming. A number of techniques have been suggested that attempt to reduce the frustration of debugging. Some of these techniques include:

> 1) Build the program in modules. Make sure each module works correctly before adding it to the program.
>
> 2) Have other programmers check the code.
>
> 3) Make a flow chart of the conceptual model to help in writing the code.
>
> 4) Examine the output carefully to ensure reasonableness of results.

5) Document the code fully so that errors can be
tracked down quickly and so that others can
understand the code.

In an attempt to apply some of these techniques, the processes in
the SUPT system were logically separated into tasks which could be
written as computer subroutines. The appropriate computer language for
each routine was then selected. This selection was based on which
language was capable of performing the routine most efficiently. The
routines which handled calendar events and the allocation of resources
were written in the SLAM simulation language. Tasks which involved
repetitive computations and complicated conditional branching were
programmed in FORTRAN. Throughout the model development, the simulation
was constructed in modules, which were then checked for proper logic by
each programmer.

Flowcharts of the logic required for major program modules, such as
the one presented in Figure 3, page 3-8, were prepared before the actual
code was written. The main purpose of this technique is to prevent
logic errors from becoming embedded in the program. Logic errors, which
may be syntactically correct, can be the most difficult to detect. The
flowcharts were particularly helpful in determining whether all possible
logic paths in the SUPT program were properly accounted for in the code.

As the modules were added to the simulation, the resulting output
was checked. The printouts were checked for reasonableness and were
verified as producing numbers which matched the probability distribu-
tions contained in the program. For example, in primary phase the
simulation was programmed to eliminate students at a mean rate of 13.8
percent with a standard deviation of 3.9 percent. Therefore, as a

3-23

verification measure, the actual number of washouts in each phase was recorded. The output reflected the intended distribution for attrition. The remaining distributions and conditional branches in the program were similarly checked.

Both the SLAM code and the supporting FORTRAN routines were fully documented. This was a great aid in tracking down errors. It is also very helpful when one goes back to examine a portion of the program written weeks or months earlier. Anyone at least minimally comfortable with reading computer programs should be able to follow the source listings in Appendices C and D.

The techniques discussed were all used in an effort to produce a fully verified model. Working concurrently with the verification process is another critical process in model development, the validation process.

Validation

Validation is concerned with whether the model is an accurate representation of the real system. There is thus a subtle difference between verification, where the goal is a model that matches the designer's intentions, versus validation where the goal is a model which accurately reflects the system. Validation was a difficult task in this study since SUPT is merely a proposed system. The analysts determined that a reasonable approach was to run the simulation with the values ATC expects to use (i.e. production goal, number of airplanes, etc.) and compare the output of the model with the values ATC expects to realize from the SUPT program. This process was closely tied in with the verification process.

3-24

A major part of validation is the calibration process, whereby the model results are compared with those of the proposed system and adjustments are made as necessary (2:383). As an example, in the model the students were finishing primary phase too quickly. It was discovered that the substantial academic requirements in primary phase had not been given proper consideration in the model. After incorporating academic time into the model design, the model output more closely matched the baseline output.

Validation is actually a continuous process. It starts with the hypotheses about system behavior formulated during development of the conceptual model. It requires comparison of output in light of these hypotheses. Most of all, it requires that the results of the simulation model are reasonable. Steps taken throughout the model building process which test the input distributions and program modules all contribute to model validity and confidence in the final results of the study.

The model has high face validity if the basic model and its output appear to be reasonable to model users and to others who are knowledgeable about the real system (2:385). The model was judged to have high face validity based on a subjective evaluation by the developers and personnel at ATC knowledgeable about the SUPT system. The results agree well with ATC expectations. The baseline model yields: Average days to complete primary phase = 90 out of 105 days allotted, Average days to complete basic phase = 93 out of 105 days allotted, and Annual pilot graduation rate = 1930 pilots per year. These results are quite reasonable in light of the fact that the model uses an heuristic scheduling algorithm which tends to push students through the system in minimum time given the amount of aircraft and

3-25

simulator resources available.

Summary

The proper design and implementation of a model of the problem being studied is an integral part of a systems analysis. In this chapter, the steps taken to produce such a model are presented. The first step is to convert the real situation into logical relationships that can be programmed using a simulation language. In this regard, the the steady-state operation of SUPT was converted into a network of logical relationships. Since many of the factors in these relationships were based on real-world, stochastic outcomes, data was collected and analyzed. This analysis centered on the determination of the type of distribution to which the data belonged. By plotting histograms of the data and attempting to fit these plots to a probability distribution, the data appeared to fit a normal distribution. To verify this assumption of normality, the Kolmogorov-Smirnov Goodness-of-Fit test was used. Based on the results of this test, the values of the stochastic factors used in the model were drawn from normal distributions using parameters computed from the historical data.

Having verified the type of distributions to use for the stochastic factors and determined the logical and structural relationships which support the SUPT program, the next step was to code this information into a simulation language. Coincident with this action, as each sub-program was written it was verified to insure it performs as desired. In addition, as each portion was added to the model, the output of the model was reviewed to insure it agreed with the data supplied by ATC. This step ensured the validity of the model.

IV. Experimental Design

Selection of Factors to be Varied

A list of 30 controllable variables and 15 random variables in the SUPT model was compiled. This list is presented in Table VII.

Table VII

List of Model Variables

Controllable Variables	Random Variables
Production Goal	T-46 Attrition Rate
Number of T-46's	T-38 Attrition Rate
Number of T-46 Sims	TTB Attrition Rate
Number of T-38's	T-46 Ground Abort Rate
Number of T-38 Sims	T-38 Ground Abort Rate
Number of TTB's	TTB Ground Abort Rate
Number of TTB Sims	Laughlin T-46 Wx Rate
Number of T-46 Instructors	Laughlin T-38 Wx Rate
Number of T-38 Instructors	Williams T-46 Wx Rate
Number of TTB Instructors	Williams T-38 Wx Rate
Ratio of Students to FAR/TTB	Reese T-46 Wx Rate
Days allowed for PCS	Reese TTB Wx Rate
Days between class entry	Vance T-46 Wx Rate
Days allowed for Primary	Vance TTB Wx Rate
Days allowed for Basic	Columbus T-46 Wx Rate
T-46 Sorties required	Columbus TTB Wx Rate
T-46 Sims required	
T-38 Sorties required	
T-38 Sims required	
TTB Sorties required	
TTB Sims required	
Length of a T-46 Sortie	
Length of a T-46 Sim	
Length of a T-38 Sortie	
Length of a T-38 Sim	
Length of a TTB Sortie	
Length of a TTB Sim	
T-46 Turnaround Time	
T-38 Turnaround Time	
TTB Turnaround Time	

The random variables listed govern such things as student attrition, ground maintenance abort rates, and weather cancellation rates. It is not appropriate to vary attrition, maintenance

cancellations, or weather cancellations since these variables already include the variance that exists in the historical data. However, since the distributions used to represent these rates were drawn from historical data which is a mere sample of the overall population, it is appropriate that a portion of the sensitivity analysis be devoted to determining what impact varying the parameters of these distributions about the calculated values will have on overall system performance. This portion of the analysis will be addressed in Chapter 5.

Of the 30 controllable variables, the majority are governed by the SUPT syllabus. These factors include: number of flying sorties and simulator sessions required per phase, the length of a flying sortie or simulator session, and the number of training days allotted to each phase. It is not appropriate to vary these syllabus items since these factors have been set by ATC after careful study and have been deemed to be at the correct levels to produce a qualified pilot. The remaining factors represent production goals and resources. Instructor pilot and T-38 resources were not selected for this analysis since these are existing resources whose numbers are not likely to change significantly.

Six factors emerged as seemingly appropriate for further study: Production goal, Student ratio to FAR/TTB, Number of T-46's, T-46 simulators, TTB aircraft, and TTB simulators. The resource factors included in this list, T-46's, TTB's, and their related simulators, have not yet been acquired and as such, their numbers are subject to the outcome of current and future budget decisions. Similarly, the production goal and the proper ratio to send to FAR versus TTB are still topics being discussed by ATC planners.

Choice of Factor Levels

Our experimental objective is to make a general investigation of the selected factors to determine which factors have a significant impact on the SUPT system and if there are any significant interactions between factors. An interaction exists when the system's response to one factor depends on the level of another factor or factors. This objective is most easily accomplished by using two levels for each factor of interest. This design requires the least amount of computer runs to obtain the necessary information. The baseline level for each factor, Level 1, represents the factor levels currently anticipated by ATC. Level 2 for each factor represents other factor levels being discussed by ATC, or in the case of resources, are levels which show a ten percent reduction in airframes and a reduction in simulators of two. The ten percent reduction in airframes (T-46's and TTB's) represents two possible scenarios. Since ATC has not accepted delivery of the T-46 or the TTB aircraft, two plausible situations are: a delay in delivery of the new aircraft or a budget re-allocation which reduces the total number of airframes available to ATC. The reduction of simulators from eight to six per phase is used to examine the effects of two possible scenarios. The first scenario suggests that in an effort to trim the ATC budget, appropriations for two of the T-46 or TTB simulators may be cut. These highly technical devices are extremely expensive and it is very likely that in a budget trimming measure, money for some of these devices could be cut. The second scenario attempts to add a real-world flavor to the experiment by suggesting that two simulators are down due to maintenance failures. The production goal of 2200 is a future pilot production goal anticipated by ATC and openly discussed by Brigadier

4-3

General William M. Charles, Jr., the former ATC Deputy Chief of Staff for Plans.(3:42) The 45/55 mix for students going to FAR/TTB is used to test the outer limits of the capability of the FAR program as it is currently designed. Current ATC projections find that FAR will, at its best, be able to support the 40/60 mix. The levels chosen for the factor analysis are presented in Table VII.

Table VIII

Factors and Levels for the Experiment

Factor	Level 1	Level 2
(A) Production Goal	1910	2200
(B) FAR/TTB Student Ratio	40/60	45/55
(C) Number of T-46's	409	368
(D) Number of T-46 Sims	8	6
(E) Number of TTB's	225	202
(F) Number of TTB Sims	8	6

Screening Designs

Screening designs determine which of the factors chosen for study will have a significant impact of the system. Performing a full factorial analysis of the six factors chosen, each at two levels, would require 2^6, or 64 runs. Since more than one replication is required to assess the stochastic variation in the response measures, the number of total computer runs required would actually be a multiple of 64 runs. The SUPT model is very large and complex. At any one time there may be 2500 or more students in the system each requiring numerous simulator sessions and flying sorties which are subject to maintenance and weather cancellations. This simulation requires a very large amount of computer time. For example, when running this model on the CDC 6600 Cyber, it takes approximately 32 minutes of processing (CPU) time to accomplish one replication of the program. Therefore, all attempts must be made to

4-4

keep the number of runs to a minimum.

If the effects of the higher-order interactions, those interactions between three or more factors, are assumed to be negligible, then the information on main factors and two-way interactions can still be obtained by only running a fraction of the full experiment. Fractional factorial designs are very useful for screening significant fa tors and as a consequence of their use, the number of runs required to conduct a factorial experiment are reduced. In a fractional design the higher order interactions are confounded with the effects of interest. This means that these higher-order effects cannot be distinguished from main effects and two-way effects. Interactions which are confounded against other effects are appropriately called aliases (9:327).

The size of the fraction being run determines how much confounding of effects occurs. For this experiment, a one-fourth and a one-eighth fraction were chosen. The one-eighth fraction of a 2^6 experiment produces what is called a resolution III design. In this design main effects are aliased against two-factor interactions and two-factor interactions are aliased with each other (9:329). In the one-fourth fraction of a 2^6 experiment, a resolution IV design is produced. Here, main effects are not aliased with any other main effects or two-factor interactions. However, two-factor interactions are still aliased with each other.

In the one-fourth fraction of a 2^6 experiment, called a 2^{6-2} Resolution IV design, the design matrix used in the statistical analysis and construction of runs required is created by laying out a full 2^4 design and then using "generators" to fill in the columns for the fifth and sixth factors. The generators from Montgomery (9), Table 11-8 were

used to create the design matrix in Table IX. This table also reveals, in the right-hand column, the factors which will be set at Level 2 for that particular run.

Table IX

2^{6-2} Resolution IV Design Matrix
Generators: E=ABC, F=BCD

	(1)	A	B	C	D	E	F	AB	AC	AD	BC	BD	BF	DE	ABD	ABF	Runs
(1)	1	-1	-1	-1	-1	-1	-1	1	1	1	1	1	1	1	-1	-1	(1)
a	1	1	-1	-1	-1	1	-1	-1	-1	-1	1	1	1	-1	1	1	ae
b	1	-1	1	-1	-1	1	1	-1	1	1	-1	-1	1	-1	1	-1	bef
c	1	-1	-1	1	-1	1	1	1	-1	1	-1	1	-1	-1	-1	1	cef
d	1	-1	-1	-1	1	-1	1	1	1	-1	1	-1	-1	-1	1	1	df
ab	1	1	1	-1	-1	-1	1	1	-1	-1	-1	-1	1	1	-1	1	abf
ac	1	1	-1	1	-1	-1	1	-1	1	-1	-1	1	-1	1	1	-1	acf
ad	1	1	-1	-1	1	1	1	-1	-1	1	1	-1	-1	1	-1	-1	adef
bc	1	-1	1	1	-1	-1	-1	-1	-1	1	1	-1	-1	1	1	1	bc
bd	1	-1	1	-1	1	1	-1	-1	1	-1	-1	1	-1	1	-1	1	bde
cd	1	-1	-1	1	1	1	-1	1	-1	-1	-1	-1	1	1	1	-1	cde
abc	1	1	1	1	-1	1	-1	1	1	-1	1	-1	-1	-1	-1	-1	abce
abd	1	1	1	-1	1	-1	-1	1	-1	1	-1	1	-1	-1	1	-1	abd
acd	1	1	-1	1	1	-1	-1	-1	1	1	-1	-1	1	-1	-1	1	acd
bcd	1	-1	1	1	1	-1	1	-1	-1	-1	1	1	1	-1	-1	-1	bcdf
abcd	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	abcdef

Using the same generators, the full alias structure for this design was created and is presented in Table X. Similarly, the design matrix and alias structure for the 2^{6-3} Resolution III design were created and are presented in Tables XI and XII.

4-6

Table X

Aliases for 2^{6-2} Resolution IV Design

(1)	ABCE	BCDF	ADEF
A	BCE	ABCDF	DEF
B	ACE	CDF	ABDEF
C	ABE	BDF	ACDEF
D	ABCDE	BCF	AEF
AB	CE	ACDF	BDEF
AC	BE	ABDF	CDEF
AD	BCDE	ABCF	EF
BC	AE	DF	ABCDEF
BD	ACDE	CF	ABEF
CD	ABDE	BF	ACEF
ABC	E	ADF	BCDEF
ABD	CDE	ACF	BEF
ACD	BDE	ABF	CEF
BCD	ADE	F	ABCEF
ABCD	DE	AF	BCEF

Table XI

2^{6-3} Resolution III Design Matrix
Generators: D=AB, E=ABC, F=AC

	(1)	A	B	C	D	E	F	BC	Runs
(1)	1	-1	-1	-1	1	-1	1	1	df
a	1	1	-1	-1	-1	1	-1	1	ae
b	1	-1	1	-1	-1	1	1	-1	bef
c	1	-1	-1	1	1	1	-1	-1	cde
ab	1	1	1	-1	1	-1	-1	-1	abd
ac	1	1	-1	1	-1	-1	1	-1	acf
bc	1	-1	1	1	-1	-1	-1	1	bc
abc	1	1	1	1	1	1	1	1	abcdef

Table XII

Aliases for 2^{6-3} Resolution III Design

(1)	ABD	ABCE	ACF	DCE	BEF	BCDF	ADEF
A	BD	BCE	CF	ADCE	ABEF	ABCDF	DEF
B	AD	ACE	ABCF	BDCE	EF	CDF	ABDEF
C	ABCD	ABE	AF	DE	BCEF	BDF	ACDEF
AB	D	CE	BCF	ABDCE	AEF	ACDF	BDEF
AC	BCD	BE	F	ADE	ABCEF	ABDF	CDEF
BC	ACD	AE	ABF	BDE	CEF	DF	ABCDEF
ABC	CD	E	BF	ABDE	ACEF	ADF	BCDEF

It is clear from these tables that the runs required by the Resolution III design are all included in the Resolution IV design. Both designs have limitations. What is gained by the reduction in runs required is lost, to some extent, in the amount of confounding of effects. Higher-order interactions can be very difficult to explain and they rarely occur in real world systems. Thus, _if_ higher-order interactions are negligible then the fractional designs chosen should yield the desired information on main effects and two-way interactions.

Another important characteristic of the designs used in this experiment is that they are orthogonal. This means that the design matrices used in the experiments are orthogonal matrices. A matrix is orthogonal if its transpose equals its inverse. A simple method for determining if a matrix is orthogonal is to check that: (a) each column of the matrix sums to zero, (b) the product of any two columns sums to zero, and (c) the sum of the squared elements of any column does not equal zero. (10:36)

The advantage to using such a design in this experiment is that since the design is orthogonal, the coefficients of the general linear model (i.e. the beta values) are uncorrelated. This situation allows independent statistical tests to be accomplished to determine the significance of individual factors and their interactions within the model.

Selection of Response Variables

To adequately measure the full system's response to changing factors, ten indicators were selected. They are the days to complete primary phase at each of the five bases and the days to complete all

4-8

ATC and the USAF have control over the inputs of these factors and information on the acceptable range of these inputs could be useful information to decisionmakers.

Sensitivity to Pilot Production Goal.

The pilot production goal was run over a range of 1910 through 2200 graduates per year to determine at which level the system appeared to be significantly impacted. The specific levels chosen were 1910, 2000, 2100, and 2200, thus requiring 24 simulation runs for this portion of the sensitivity analysis. The response variable deemed most appropriate for this analysis was the mean number of days required to complete SUPT, averaged across all five bases.

The ANOVA for the various production goals appears on page B-21. The probability value (p-value) equals zero; thus, there is a significant difference in system response across the four levels chosen. Duncan's Multiple Range Test provides more information on individual levels. This test indicates a significant difference between all possible pairs of levels run. To gain maximum insight into the effect of changing production goals, the total system response must be examined. Accordingly, all of the output from the simulation run should be examined to determine if there are any other significant results aside from those affecting the primary measure of effectiveness.

One response which appeared to be significantly affected by a change in levels was the number of students finishing primary phase late. Figure 8 shows a plot of number of students late in primary phase (in the course of a 75 day run) versus the production levels chosen. The system appears to handle a production goal of up to 2000 graduates

5-9

SUPT model is to various levels of the factors which were identified as being significant. The goal in this type of analysis is to identify at which level or levels the steady-state operation of the system is significantly affected. To accomplish this, a sensitivity analysis was conducted on each of the factors found to be significant. Each of the factors was tested in isolation, that is, all other factor levels were held constant while the selected factor was varied over a predetermined range.

The same tactical planning factors used in the screening design were employed in the sensitivity analysis runs. Six replications of each run were performed. Furthermore, the replications were paired with replications from antithetic sets of random number streams. This also follows the routine set in the factorial experiment.

The appropriate statistical tool for differentiating between the effects of various factor levels is the one-way, fixed-effects ANOVA. The same assumptions required for use of the linear statistical model, the foundation of the ANOVA method, apply as stated earlier. When the ANOVA results indicate that there is a significant difference in response due to the factor levels chosen, the researcher can make further inferences about individual levels using one of several comparison methods available. The method chosen in this study was Duncan's Multiple Range Test. This test has been found to be very effective at detecting differences between levels when significant differences exist. (9:68)

All of the factors found to be significant in the factorial design were examined in this sensitivity analysis since they each contribute to the operation of the SUPT system in their own unique way. In addition,

relationship holds between T-46 simulators and the FAR/TTB ratio.

Looking at the results concerning days to complete SUPT for the three TTB bases, in the Resolution III design, no one factor was found to be significant across all three bases. In the Resolution IV design results, again, no significant factors were found to range across all three bases.

One possible reason for the lack of significant factors in the TTB phase may be the structure of the TTB training program itself. With a smaller student load than primary training, and a training syllabus which allows two students at a time to complete an activity as opposed to one student per training activity, the TTB phase appears to be better equipped to absorb significant changes in the levels of several of the specified factors. The standard one student-one activity syllabus of the primary and FAR training programs may be one of the causes for the occurrence of significant factors in these sections.

To summarize the results of the fractional factorial design experiments, it was found that factor A, the pilot production goal and factor D, T-46 simulators, and the AxD interaction, were significant in the primary training phase across all five UPT bases. In the FAR portion of the basic training phase, factor A, factor B (the FAR/TTB ratio), factor D, and the AxD and BxD interactions are significant. In the TTB portion of the basic training phase no factors were found to be significant.

Having identified the factors which significantly impact the operation of the SUPT system, one must now investigate those factors further.

Sensitivity Analysis

The next step in the analysis is to examine just how sensitive the

number of assests available. When this occurs, training is delayed and
the number of days required to complete all training requirements will
increase. If the ratio of students going to the FAR phase increases, the
number of students requiring FAR training increases. As the student load
increases and resources remain the same, the days necessary to complete
training will increase. It may seem odd that the number of T-46
simulators would have an effect on completion of FAR training
requirements. As seen in the analysis of primary phase factors, the
number of T-46 simulators in commission had an impact on the time
required to complete primary phase. As more students are late completing
the primary phase, the number of students entering the FAR phase varies.
This variance in the number of students per class in the FAR phase
causes the number of days required to complete training to fluctuate.
This fluctuation causes a statistically significant change in the time
required to complete FAR training. The significance of the interaction
effects in the FAR phase, AxD and BxD, can be explained in the same
fashion as the interaction effect in the primary phase. In the AxD
interation, the response to a change in T-46 simulators varies according
to the pilot production goal. If the student load is light, the response
to a change in simulators is not a severe as when the student load is
heavy. In the FAR phase, it is the response to the change in simulators
that is the significant factor. The effect of this response on FAR
training is that as the response of the change in simulators increases
in severity, the number of students entering each FAR training class
varies. As mentioned before, this variance has a direcu impact on the
mean time to complete the program. Since the FAR/TTB ratio has a direct
bearing on student load, and, hence the production goal, the same

5-6

to be significant:

(a) Factor A, pilot production goal, again appeared to be highly significant.

(b) Factor B, FAR/TTB ratio, appeared to be significant in this analysis. In this case, this factor does logically influence the outcome of the response variable and must be treated as a significant factor.

(c) Factor D, T46 Simulators, again appears to be highly significant. However, in the Resolution III design, factor D is aliased against the AxB interaction which is also highly significant.

Using the results of the Resolution IV design, the confounding problem is again resolved. Factors A and B still appear significant. In this design, factor D is shown to be highly significant in it's own right. The interaction between factors A and B and between factors B and D also are shown to be significant. The AxB interaction is aliased against the CxE interaction; however, CxE is likely to be negligible since neither factor C or factor E are shown to be significant. Similarly, the BxD interaction is aliased against the CxF interaction; however, the CxF interaction is also likely to be negligible since neither factors C or F are significant. All other factors and interactions do not appear to be significant.

As in the primary training phase, the significant factors in the FAR phase are a product of the program design. As the production goal increases, the number of students entering the FAR phase increases. Since none of the resources in the FAR phase are varied, as the number of students increases, a greater demand is placed on these limited assets. The program eventually reaches a point where demand exceeds the

are highly significant. The advantage of comparing the Resolution IV against the Resolution III results lies in the resolution of the confounding effects of the Resolution III design. In this case, the confounding of factor A with the BxD and CxF interactions is resolved in the Resolution IV design since factor A is shown to be highly signifi- cant in it's own right. The significance of factor D is resolved in a like manner. In the Resolution IV experiment, Factor B is not a significant factor.

The structure of the primary phase training program supports the significance of the production goal and number of T-46 simulators. As the number of students entering the program in the primary phase increases in response to a higher production goal, a greater demand is placed on the available resources. Once the demand exceeds the capability of the resources, training is delayed. This delay causes the number of days required to complete primary phase to increase. The simulators in this phase of training are almost constantly in use. A change in the number available will be reflected as an increase in the amount of time required to complete the phase. The significance of the interaction term, AxD, suggests that response to a change in T-46 simulators varies according to the pilot production goal and hence, the student load. This result is quite logical. When the student load is light the impact of losing T-46 simulators is not as severe as when student load is increased.

The next results to be discussed are those for the days required to complete the basic training phase at the FAR bases. Comparing the Resolution III and Resolution IV results across the two FAR bases, Laughlin and Williams, the following factors and interactions were found

5-4

uation into three sections: the data concerning the days required to complete primary phase, the days to complete FAR training, and the days to complete TTB training. Comparisons were made in each of these sections across all UPT bases involved. Based on these comparisons, from the section concerning days to complete primary phase, the following inferences can be made:

(a) Factor A, the pilot production goal, appears to be significant. However, since factor A is aliased with the BxD and CxF interactions, confounding makes it difficult to categorically state that factor A alone is significant.

(b) Factor B, the FAR/TTB ratio also appears to be a significant factor. However, in this case, the reality of the situation shows that the ratio has nothing to do with the primary phase. The confounding with the AxD and the ExF interaction may explain this unexpected result.

(c) Factor C, T46's, is not found to be significant across all five bases. This is an interesting result since it would seem logical that a ten percent change in T-46's would have a significant effect on primary training.

(d) Factor D, T46 Simulators, is significant at all five bases. However, this factor is confounded with the AxB and CxE interactions. It is therefore difficult to determine exactly which of these is significant in the Resolution III design.

(e) No other factors or interactions were significant in the Resolution III experiment for days to complete primary phase.

To get a more precise insight into the significance of the factors studied, the next step is to analyze the results of the Resolution IV design for the section concerning days to complete primary phase. The Resolution IV design clarifies the findings of the Resolution III design, those being that factor A and factor D and the AxD interaction

5-3

the model during the runs. In those runs where the model is stressed, (i.e. the number of simulators and aircraft available, or student load severly restrict the activities of the system) the variance tends to be larger than the variance measured when the system is not being stressed.

Based on the results of Bartlett's test, the assumption could be made that the Analysis of Variance technique is not appropriate for this situation. However, this assumption is a bit presumptuous. According to Montgomery, "when the assumption of homogeneity of variance is violated, the F-test (the basis of the Analysis of Variance method) is only slightly affected in the balanced fixed effects model." (9:91) Since this analysis employs a balanced fixed effects model, this statement applies and the use of ANOVA in this analysis is supported.

Based on the support provided above, the ANOVA method does appear to adequately explain the variance within and across the runs. The model supports the assumption that the error terms are normally and independently distributed. Although the variances do not appear to be homogeneous, the F-test in the ANOVA is only slightly affected and still provides a good explanation of the variance in the model. By establishing support for the use of the ANOVA method on the data collected one gains confidence in inferences derived from the statistical tests.

Analysis of the Factorial Experiment

In the analysis of the results of the factorial experiments presented in Appendix B, the Resolution III data was examined first to determine the presence of any significant factors or interactions. Additionally, the Resolution III data was divided for purposes of eval-

V. <u>Analysis of Experimental Results</u>

<u>Model Adequacy</u>

Before discussing the results of the fractional factorial design experiments, the adequacy of the statistical technique used in this analysis must be addressed. The Analysis of Variance (ANOVA) method was used in this analysis to assess the impact of the factors considered. Briefly, the ANOVA method is based on the linear statistical model. This model describes the observations of an experiment as being composed of an overall mean, a 'treatment' effect from the particular run from which an observation was drawn, and a random error component. (9:44) In general, when employing the ANOVA method, certain assumptions must be made about the underlying data structure. These assumptions include: (1) the error terms are normally and independently distributed, and (2) the variance across all runs is constant.

The statistical results for the Resolution III design are presented on pages B-1 through B-10 of Appendix B. The results of the Resolution IV design are presented on pages B-11 through B-20. The plots of residuals (difference between an observation and the run mean) versus the fitted data included in the analysis fail to show a noticeable trend or relationship. This supports the first assumption, that the error terms are indeed normally and independently distributed. Another statistical measure included in the analysis is the Bartlett's test for homogeneity of variance. In all twenty statistical runs of the experiment, the model failed Bartlett's test at a 0.05 level of significance, showing that the variance across the runs is not homogeneous. The lack of homogeneity across the runs may result from the different states of

5-1

Summary

A subjective screening of the 30 controllable variables and 15 random variables in the SUPT model was made to determine which factors would be examined in the study. Six factors stood out as candidates for further examination. A two-level design was chosen since at this stage of the analysis only main effects and two-way effects are of interest. Furthermore, a fractional design was used which reduced the amount of computer runs required yet still yielded the desired information. Factor levels were chosen based on ATC's interests. The appropriate run length and number of replications required were computed. The experiment was run and the results of the antithetic runs are presented in Appendix A. The data sets for the Resolution III and Resolution IV designs were run in a fractional factorial Analysis of Variance. The results are presented in Appendix B and are discussed in the following chapter.

and nearly identical to the variance obtained using common random number streams at the fifth base. The levels of significance using an F test were $p=0.0718$, 0.2345, 0.3321, and 0.4712. Each antithetic sample requires two replications, which are then averaged. Thus, it must be decided whether the loss in degrees of freedom and power of the test are worth the variance reduction obtained. This decision can be made using the Operating Characteristic Curves for a Fixed Effects Model Analysis of Variance found in many statistics books. It was determined that in this experiment the loss in power due to sample size would be insignificant and would be more than offset by the amount of variance reduction obtained. Using the largest sample standard deviation obtained with antithetic sampling (again, at Vance), the following formula was employed to determine the actual number of replications required for the experiment:

$$N_r = 2\ \frac{s(t_{\alpha/2}+t_{\beta/2})^2}{d}\ +1 = 2\ \frac{.8544(2.571+2.015)^2}{5}\ +1 = 2.23$$

Thus, three samples (requiring six antithetic replications) are required to detect a difference in response of five days with the level of significance and power discussed previously. Therefore, for the Resolution IV design, 96 (6*16), replications of the simulation were required. A subset of these, 48 (6*8), was required for the Resolution III design.

number of replications required for statistically significant results. The reason ten random number streams were chosen was to investigate the efficacy of using one of two variance reduction techniques: common random number streams and antithetic random number streams. The goal of variance reduction techniques is the reduction of the variance of the sample mean response. This increases the reliability of the results and reduces the number of replications of each run required (11:484). The use of common random number streams or correlated sampling means "that for each replication, the same random numbers <or seeds> are used to simulate <each stochastic factor>". (2:456) Therefore, for each replication, the point estimates of the response variable are no longer independent, but are correlated. However, since "independent streams of random numbers are used on any two different replications, <the estimates of the response variables> are mutually independent." (2:457) The use of common random number streams induces a positive covariance between runs, resulting in a reduction of the variance of the difference between runs. To insure that "each random number used in one replication is used for the same purpose in the next replication, the use of the random numbers must be synchronized."(2:458) This use of synchronization, especially in a network system like this one, insures that each replication faces the identical system operation conditions.

Antithetic random number streams were also investigated. With antithetic sampling a negative covariance between replications of the same run is desired. Thus, the variance of the sample mean for each run is hopefully reduced. The variances obtained using both variance reduction techniques were compared. The variance of total training days required was smaller using antithetic sampling at four of the five bases

4-11

of these hypotheses, a difference of five training days (one week) in the measure of effectiveness should be detected with 95 percent confidence. The beta level was set at 0.10, representing a ten percent chance of committing a Type II error, or failing to reject a false hypothesis. The following formula was employed and the largest sample standard deviation of the five bases (at Vance) was used:

$$N_1 = \frac{s(z_{\alpha/2} + z_{\beta/2})}{d}^2 = \frac{7.21(1.96+1.645)}{5}^2 = 27.02 \text{ days}$$

Thus, the minimum length of run required is 27.02 days. To increase the statistical accuracy of the experiment, the analysts determined that at least five classes should graduate from the program during the course of the model's operation. Therefore, the run length after clearing statistics was set at 75 days.

There are basically two options for obtaining a sufficient number of observations to achieve statistical significance. One method is to extend the length of a run and collect statistics at various intervals during the course of the run. Each one of these intervals is called a "batch." However, when this method is used, the observations do not constitute a random sample. The responses are not statistically independent since the response observed at the end of one interval has been affected by the outcome of the previous interval. Such a sequence of random samples is said to be "autocorrelated." The preferred method for obtaining a sufficient number of observations, which avoids the problem of autocorrelation, is the use of independent replications.

Ten replications of the model, using a different random number stream for each stochastic factor, were used to determine the exact

4-10

SUPT requirements at each of the five bases. To provide an accurate measure of the system response in the FAR and TTB phases, the five indicators measuring the days to complete all SUPT requirements at each of the five bases were subdivided in a FAR group and a TTB group. To complete this phase of the experiment, the tactical planning which dictates how the individual runs will be made must be accomplished.

Run Length and Sample Size Required

The SUPT simulation was initialized with students with various amounts of the flying program completed to allow the simulation to reach steady-state operation more quickly. The first step toward determining model run length involved allowing the model to run for a long time duration. During this run, a plot was generated showing the mean and variance of days to complete all training requirements at Laughlin AFB. This plot showed that the variance stabilized after 240 training days (almost one year). This stablization of the variance inferred that the system had reached a steady-state condition. Thus, for future runs all statistical registers in the simulation model were cleared after 240 days of operation to allow the results to show the expected system response in steady-state. Note that after 240 days all of the students which were initialized into the system have graduated; thus, any possible bias introduced in the initialization process has been reduced.

The run length required after clearing statistics was determined by examining the standard deviation of the number of days to complete training requirements. The null hypothesis is that there is no difference in the mean response between runs. The alternative hypothesis is that a difference does exist. In accomplishing the test

4-9
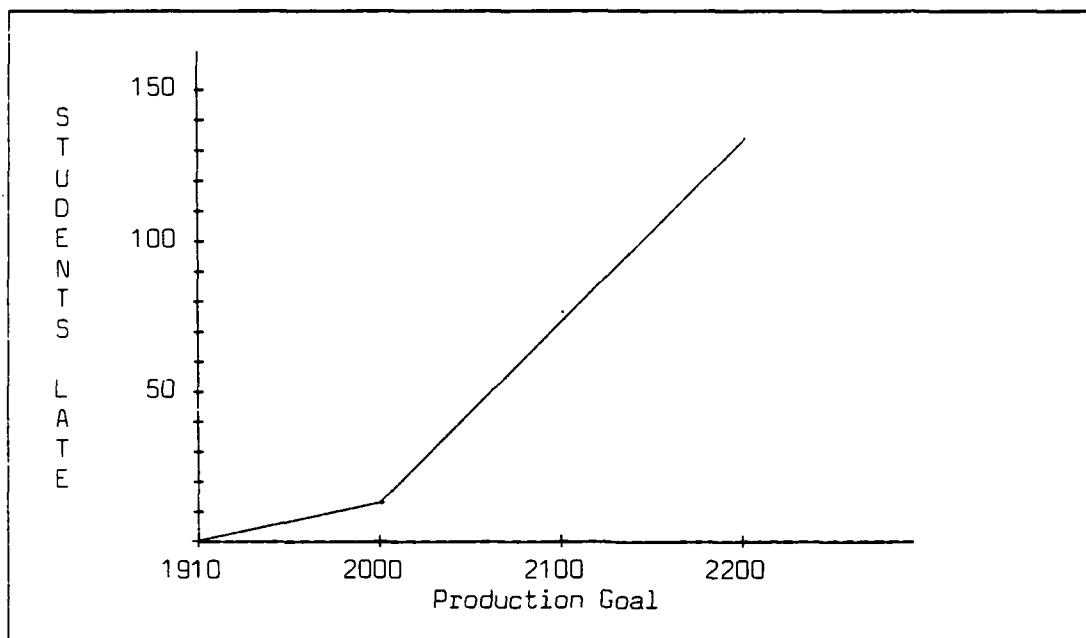
Figure 8.   Students Late vs. Production Goal

reasonably well.   After 2000 the number of late students increases
rapidly.   It should be noted that students late in primary phase were
able to make up time in the basic phase and still graduate on
time.   Nevertheless, having a significant number of students late in
primary phase is not an acceptable mode of operation.

   Sensitivity to FAR/TTB Ratio.

   The FAR/TTB ratio was run over a range of 40/60 to 45/55 percent to
gain more insight into the impact changes in this factor have on the
system response.   This factor is one of prime interest to ATC
planners.   One can envision circumstances in which this ratio may have
to be shifted in the future to respond to a higher demand for FAR
trained pilots or a higher demand for TTB trained pilots.   The specific
levels chosen for this analysis were 40/60, 41/59, 43/57, and 45/55.
The reason that the 42/58 and 44/56 levels were not run is that class

sizes computed based on these ratios were virtually the same as ones for the levels chosen due to rounding off of class sizes. Integer numbers for class sizes were desired and the 42/58 ratio produced the same class sizes as the 41/59 ratio. Similarly, the 44/56 ratio produced virtually the same class sizes as the 43/57 ratio. Using the four levels chosen, 24 simulations were again required for this portion of the sensitivity analysis.

The response variable chosen as most appropriate for this situation was the mean number of days to complete FAR training. This measure was chosen since shifting the ratio from 40/60 to 45/55 would have the greatest impact on FAR training. Also, if a composite measure, such as the mean number of days to complete SUPT across all five bases were chosen, the increased days required for FAR would be offset by a decreased number of days required for TTB training.

Page B-22 shows the ANOVA results for these runs. Again, a significant difference in system response between runs is observed. The value of a comparative test, such as Duncan's test, is evident in these results. Duncan's test shows that the only level which is significantly different than the others is the 45/55 ratio. This result indicates that only when the ratio is shifted as far as 45/55 is the SUPT system, as modeled here, significantly impacted.

Sensitivity to Reduction of T-46 Simulators.

Since the screening of factors conducted in the experimental design showed the level of T-46 simulators to be significant, this factor was chosen for further study. The levels chosen for this portion of the analysis were eight simulators (the nominal value), seven simulators (a

reduction of one), and six simulators (a reduction of two). As men-
tioned earlier, the purpose of examining these particular levels was not
solely to investigate the impact of reduced simulator funding and allo-
cation, but also to examine the impact that a prolonged maintenance
failure for one or two simulators would have on the system. The
response variable chosen as most appropriate for this case was the mean
number of days required to complete primary phase averaged across all
five UPT bases since T-46 simulators exist at all five of these bases.

Eighteen simulation runs were required for this analysis since the
model was run at three different levels for T-46 simulators. The ANOVA
for the results of these runs is presented on page B-23. The p-value of
zero indicates that there is a highly significant difference in system
response between the three levels chosen. Furthermore, Duncan's test
shows that the differences between each pair of levels are also
significant.

Further insight into the impact of this factor was gained when the
remaining output variables of the simulation runs were examined. As in
the section on sensitivity to production goals showed, there were again
significant numbers of students late in primary phase when T-46
simulators were reduced. A plot of students late in primary phase (for
a 75 day run) versus reduction in simulators is shown in Figure 9. As
the figure shows, there is a significant increase in late students when
even one simulator is removed. A reduction of two simulators yields a
dramatic increase in the number of late students. Thus, the SUPT
system, as modeled here, is very sensitive to the loss of a T-46
simulator for a prolonged period of time. Whether the loss of a
simulator for a lengthy amount of time is a serious possibility is not

5-12
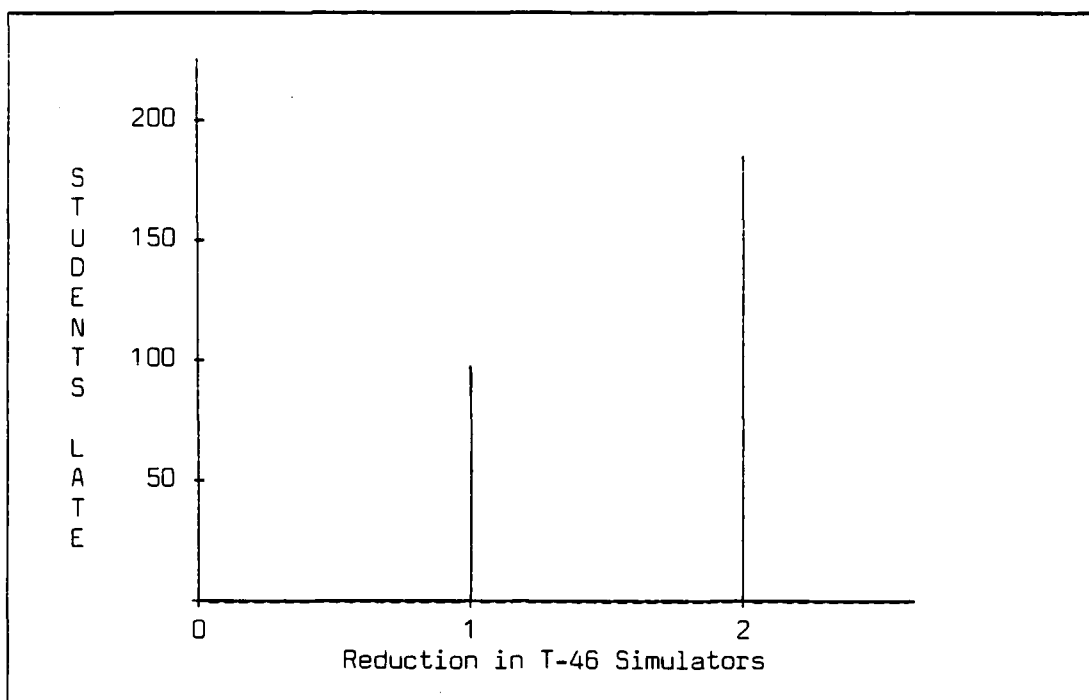
Figure 9. Students Late vs. Reduction in T-46 Simulators

within the scope of this study. However, the mere significance of this factor may warrant careful contingency planning for a reduction in the level of simulators on line.

Sensitivity to Probability Distributions

Having examined the factors identified in the screening design in further detail, it is also necessary to investigate the sensitivity of the model to changes in some of the parameters drawn from the probability distributions used in the model. The reasons for examining model sensitivity to these distributions are twofold: First, the validity of the results of this analysis is increased when a better understanding is gained of the model's response to shifting distributions. For example, if a distribution is shifted and the model shows no significant response then one may be reasonably confident that

the results of this analysis would still be valid if the distribution in question were to shift such an amount. However, if the model exhibits sensitivity to a certain change in a probability distribution then one knows to take caution in extrapolating the results of this study when the distribution in question changes. Secondly, aside from validity considerations, valuable information about the system's sensitivity to a change in one of the distributions can be gained through a sensitivity analysis.

The approach taken in determining the levels to be run was to first shift the mean of the normal distribution one standard deviation to the left then one standard deviation to the right. Then a new standard deviation was assigned to each of these new normal distributions by using the coefficient of variation for the original distribution. The coefficient of variation is equal to the standard deviation divided by the mean of the distribution. Once the coefficient of variation was calculated, it was multiplied by the mean of the proposed distribution to compute a standard deviation for the proposed distribution.

Next, the original data for the distribution in question was tested against the new mean and standard deviation using the Kolmogorov-Smirnov Goodness-of-Fit Test. In each case, the new parameters failed the K-S test. This test was conducted to ensure that the parameters of the distributions being tested were indeed statistically different from those used in the model. This is an important consideration since if the new parameters passed the test one would not expect a significant difference in response and a sensitivity analysis would be pointless.

Sensitivity to Attrition Rates.

The first probability distribution chosen for sensitivity analysis was primary phase attrition. It is particularly important to examine this distribution since the attrition in this phase was found to waiver significantly over the course of the fifteen years of data collected for this analysis. The attrition distribution for basic phase was not investigated since it has remained stable and relatively small over the course of the years collected.

The original distribution was shifted up and down one standard deviation using the methodology described in the previous section. Eighteen runs were then required since the attrition distribution was examined at three different levels. The response variable chosen for this analysis was the mean number of days required to complete primary phase averaged across all five UPT bases. The results of the ANOVA are shown on page B-24.

The small p-value indicates that there 'is a significant difference in system response between the distributions chosen. Furthermore, Duncan's Multiple Range Test shows that each of the distributions elicits a significantly different response in a pairwise comparison. The important fact to note is that the system is sensitive to a one standard deviation shift in primary phase attrition. This result is logically expected since there is a direct inverse relationship between attrition and student load. When the attrition rate is low the student load will be higher and vice versa. Also important to note is that the results of this study are valid only when attrition is near the hypothesized level.

Sensitivity to T-46 Maintenance Abort Rate.

The next distribution chosen for investigation was the distribution of ground maintenance abort rates for the T-46 aircraft. The distribution for T-46 aborts was derived from historical data on T-37 abort rates. ATC is using this same data in their planning for the T-46 trainer. Therefore, it is important to examine the model's sensitivity to a change in this distribution in case the actual T-46 abort rate turns out to be significantly higher or lower than the distribution used in the model. Distributions which were one standard deviation higher and one standard deviation lower than the derived distribution were used for this portion of the analysis.

The appropriate response variable for these runs is the mean time to complete primary phase requirements since this is the only phase of training which uses the T-46. ANOVA results are shown on page B-25. This time the p-value is quite high, at 0.5920. This indicates there is no significant change in response for the three distributions used. The importance of this finding lies in the fact that SUPT system is insensitive to as much as a one standard deviation change in T-46 ground maintenance abort rates. This is a good result in support of the validity of this study since the T-46 may very well not exhibit the same abort rate as the T-37. Thus, if the actual rate is as much as one standard deviation different from the hypothesized distribution then the results of this thesis should be still valid.

Sensitivity to TTB Maintenance Abort Rate.

The last distribution run in the sensitivity analysis was the distribution of TTB ground maintenance abort rates. The distribution

5-16

for the TTB aircraft was derived from data on ground maintenance aborts for the T-38 aircraft. These two aircraft types are very different so it is very important to examine the impact that a significantly different abort rate distribution would have on the SUPT model. New distributions which were shifted up and down one standard deviation from the T-38 distribution were run in this phase of the analysis. As before, eighteen additional simulation runs were required to generate the data points for the ANOVA. This time, however, the response variable chosen was the mean days required to complete SUPT at the three TTB bases.

The ANOVA results on page B-26 show that there is no significant difference in the response variable for these three distributions as evidenced by the p-value of 0.4231. Thus, should there be an actual abort rate for the TTB aircraft which is up to one standard deviation different than that used in this model, the results given are still valid.

Summary

The results of the two screening designs were examined in detail to determine which factors and interactions were significant. The Resolution III design showed certain factors to be significant, however, the degree of confounding with two-way and higher order interactions that this design allows made interpretation of the results difficult. The Resolution IV design, on the other hand, made it much easier to detect exactly which main effects and interactions were significant. The penalty paid with the use of the higher resolution design is that twice as many runs were required.

Having found the production goal, FAR/TTB ratio, and T-46 simulator level to be significant, these factors were subjected to a sensitivity analysis. It was found that a maximum of 2000 graduates per year could be easily handled by the model. Also, the model tolerated a maximum ratio of 45/55 students to be routed to FAR versus TTB training after primary phase. Lastly, even a reduction of one T-46 simulator for an extended period of time exacted a severe impact on the system.

Some key probability distributions in the model were also run in the sensitivity analysis. It was found that the model is sensitive to a change in primary phase attrition which directly affects the student load in that phase. The model was insensitive, however, to a reasonable change in either T-46 or TTB ground abort rates which speaks well for the validity of the model since in reality, either of these distributions may be quite different than the hypothesized one used in this analysis.

VI. <u>Conclusions</u> <u>and</u> <u>Recommendations</u> <u>for</u> <u>Further</u> <u>Study</u>

<u>Conclusions</u>

To date, ATC has been conducting analyses of the program design for SUPT to verify that it is capable of satisfying Air Force pilot training requirements. Although these studies do provide decision makers with sufficient information upon which to make budget and planning decisions, they are not capable of addressing the variability introduced in the system when real world data and hypothesized distributions are used. Since many of the variables in the system's operation rely on such data, any study which fails to address this variability is ignoring a very critical factor. This factor may have a significant impact on the operation of the system. It is the purpose of this analysis to provide an instrument which is capable of performing a parametric analysis of the SUPT system's operational concept.

To develop the necessary analysis tools, a thorough conceptual analysis of the SUPT program was conducted. This analysis identified the key factors within the system and revealed the logical and structural relationships between each of these factors. Using these relationships, a simulation model was developed to represent the entire SUPT program's operation. This model conducted operations at all five pilot training bases for both phase of pilot training. In addition, it provided a heuristic assignment routine that ensured a balanced student load was maintained throughout the program. Appropriate steps were taken to verify the correct operation of each module of the model program. Coincidentally, model output was properly validated to insure model results accurately reflected the operation of the system.

6-1

Using baseline figures provided by ATC planners, the model appears to accurately reflect the system operation. Based on a 105 day training schedule for the primary training phase, the model predicts that it takes an average of 90 days for one class to complete primary training. In the basic training phase, which is also based on a 105 day training schedule, the model predicts that it takes an average of 93 days to complete this phase. Looking at the system's ability to satisfy Air Force pilot training requirements, the model predicts that given the resources and student loads to attain a 1910 pilot production goal, the system will exceed that goal by approximately 20 students and produce, on average 1930 pilots per year. It bears mentioning here that the model was designed based on the worst-case assumption that if a resource is available, i.e. an instructor pilot, an aircraft, or a simulator, the student will always accomplish a training requirement. This approach allows the analysts to determine if the system design provides the absolute minimum requirements necessary to satisfy Air Force requirements. This knowledge allows decision makers to gain insight on the program's built-in ability to absorb training delays induced by lack lack of resources, weather problems, or poor student performance.

Having shown that the program design adequately satisfies ATC and Air Force training requirements, the next major step was identifying which factors of the program's operation had a statistically significant impact on the system operation. Using variables under the control of ATC and the Air Force, a factorial experiment was conducted. The variables evaluated included: (a) pilot production goal, (b) FAR/TTB ratio, (c) Number of T-46 aircraft, (d) Number of T-46 simulators, (e) Number of TTB aircraft, and (f) Number of TTB simulators. Refer to

Table VIII, page 4-4, for a listing of the factor levels used in this experiment. The results of the experiment found that the pilot production goal, the number of T-46 simulators, and the interaction between these two variables had a statistically significant impact on the operation of the primary training phase.

As the production goal increased, more students entered the primary phase. This increase in student load, without a corresponding increase in available resources, caused a significant increase in the number of days required to complete the primary phase. As a consequence of the change in the number of T-46 simulators available, students were delayed in completing their simulator training requirements. This delay caused a significant increase in the overall time required to complete the phase. As mentioned in Chapter 5, the response to a change in T-46 simulators varied with the production goal. When student loads were light, the response to a change in simulators was not as severe as when the the student load was increased. The overall impact of the interaction effect on the number of days required to complete primary training was based on the severity of the response. As the severity of the response increased, the number of days to complete the training program increased.

In the FAR portion of the basic training phase, the pilot production goal, the FAR/TTB ratio, the number of T-46 simulators, and the interaction between each of these variables had a statistically significant impact on FAR phase operation.

The impact of increased pilot production caused more students to be sent to FAR training. Since the resources in this phase remained constant, the result was an increase in the time required to complete

6-3

the phase. An increase in the FAR/TTB ratio had a similar effect on the time required to complete FAR training. The number of T-46 simulators had a indirect impact on FAR training. As the number of simulators was reduced, the time required to complete primary training increased. The variation in the number of students in each FAR training class caused a significant change in the time to complete FAR training. In some cases, the time to complete FAR was shorter than normal, while in others, the time required to complete training increased. The impact of the interaction effects is similar to that experienced in the analysis of the primary phase. The response to changes in T-46 simulators varied with changes in the production goal. As production goals increased, the severity of the response increased causing the number of days required to complete FAR training to increase. Since the FAR/TTB ratio is related to the student load, and hence the production goal, the impact of the interaction between the ratio and T-46 simulators is similar to that of the production goal and the simulators.

None of the factors tested had a statistically significant impact on the operation of the TTB phase of basic training phase. The reason for this outcome is found in the design of the TTB phase. Since training is conducted on a two-to-one ratio of students to instructors, aircraft, and simulators, the TTB program design is capable of absorbing changes and distributing their effects over the entire period of training. This causes the measure of effectiveness to remain close to its mean value. Therefore, no significant effects are realized.

Although the factorial experiment determined which variables had a statistically significant impact on the system's operation, it is of equal importance to determine at which specific factor level the

6-4

system's operation is actually affected. To accomplish this, a sensitivity analysis was conducted on the variables found to be statistically significant in the factorial experiment.

Since the pilot production goal was identified as being a significant factor, the sensitivity analysis attempted to determine at which level, on a range from 1910 to 2200 pilots per year, the system appeared to be significantly impacted. Looking at the total system reaction, the analysis found that a change in pilot production goals has a direct effect on the number of students who complete the primary phase late. Figure 8, on page 5-10, provides a graphical view of this effect. Based on the analysis, the current system design is capable of supporting a pilot production goal of 2000 pilots before the number of late students becomes significant. Looking at the number of students that are late, the analysts caution the reader that these are only students late in the primary phase. The system design adequately accounts for these late students in the basic phase, since the analysis shows that all students complete the entire SUPT training program on time.

Perhaps one of the most controversial issues in the SUPT program is the ratio of students sent to FAR and TTB training. Approval of the SUPT concept was delayed until ATC was able to assure senior Air Force staff personnel that the SUPT program design was capable of producing the required number of FAR qualified pilots. The sensitivity analysis conducted on this factor covered a range of ratios from the baseline, 40/60 mix, to a mix of 45/55. The analysis showed that system performance was not affected if the ratio is varied from 40/60 up to 45/55. However, once the 45/55 ratio was used, the analysis indicated a

END

FILMED

DTIC

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

significant impact on system operation.

Due to the ability of the TTB phase design to absorb changes in the system, the analysts did not find it appropriate to evaluate a change in the FAR/TTB ratio which increased the percentage of students entering the TTB phase.

In analyzing the impact of the loss of T-46 simulators, the analysis evaluated the response to the loss of one or two simulators. A loss of this number of simulators can be attributed to one of two factors: budget cutting measures which result in the loss of appropriations for one or two simulators, or the loss of one or two simulators due to maintenance failures. The analysis found that the loss of either one or two simulators results in a significant impact on system operations. Again, looking at the total system, the loss of T-46 simulators has a noticable effect on the number of students graduating late from the primary training phase. Refer to Figure 9, page 5-13, for a graphical representation of this effect.

The loss of even one T-46 simulator has a significant impact on the operation of the baseline model. What impact does the loss of one simulator have on the system when it is operating at a higher production goal? This question addresses the interaction effect between the production goal and the number of T-46 simulators. The results of the sensitivity analyses on production goal and number of T-46 simulators are used to answer this question. Figure 9, page 5-13, shows that the number of students late increases as the number of T-46 simulators is reduced by one and then by two. This information assumes the baseline production goal of 1910 is used. Figure 8, page 5-10, shows that as the production goal is increased, the number of students late increases.

Based on the information in these plots, as the production goal increases, the number of late students resulting from a loss of even one T-46 simulator will increase significantly over the number late in the baseline evaluation. This fact identifies the number of T-46 simulators as a limiting factor in the overall SUPT operation. ATC must consider this information carefully when making their decision on the number of T-46 simulators to appropriate.

Since the simulation model draws information from distributions based on historical data, the analysts wished to determine what effect changes in the parameters of these distributions would have on overall system operation. To work around the limited amount of data available on the SUPT program, information on the current UPT program was used with the assumption that SUPT figures will closely approximate today's figures. However, this assumption may not hold. This portion of the sensitivity analysis examined three distributions: (a) the primary attrition rate, (b) T-46 ground maintenance abort rate, and (c) TTB ground maintenance abort rate.

The primary attrition rate used in the model was developed from attrition data for the current T-37 primary phase. The analysts found a myriad of factors which impact primary phase attrition rates. These factors range from airline hiring rates to command guidance. Considering the effects of these factors, the analysts decided to analyze the effect varying the distribution parameters by one standard deviation would have on system performance. As expected, when the mean primary attrition rate is reduced by one standard deviation the system appears to operate more efficiently than in the base case. Similarly, if the mean primary attrition rate is increased by one standard

6-7

deviation, the system operates below the baseline level.

Conducting a similar analysis on the T-46 and TTB ground maintenance abort rates, the analysts found that the parameters in these distributions can change one standard deviation and not significantly affect system operation. This fact supports the assertion that even if the parameters for the abort rate should change given current data on the T-46 and the TTB aircraft, information can be extrapolated from this analysis without changing the distributions.

Recommendations for Future Study

Given the focus of this analysis, not all aspects of the current SUPT program design could be analyzed. There are several areas where further study would provide important information on system operation to ATC planners. These areas include:

(a) Reduction of the scope of the analysis to allow a detailed review of the student scheduling and training process. The worst-case scheduling heuristic used in this model is not used in real-world operations. If the scope of the model was reduced to the operation of one phase or one base, as in the Dickinson and Moses study, the system reaction to the current ATC scheduling routines could be evaluated. One possible outcome of such a study would be that the current structure of the SUPT program may not support a scheduling routine which is less restrictive than the worst case scenario used in this study. Due to the complexity of modeling the entire SUPT program, an analysis which incorporated a detailed scheduling process was not possible given available computer resources.

(b) The original model could be modified to accurately represent the actions taken if a simulator is not available for training. In the current model, if a simulator is not available students are delayed in their training program. In real-world operations, flying sorties may be substituted for the lost simulator sessions. This

6-8

increase in aircraft utilization without an increase in resources could also delay completion of training. Again, in an attempt to establish a worst-case scenario, the analysts felt that including such a real-world process would involve excessive computer processing. This modification could be incorporated along with a reduction in the scale of the model's operation.

(c) ATC is currently in need of an analysis tool which studies the dynamics involved in the transition period from the current UPT program to the SUPT program. Using this study and the analysis conducted by Major Dickinson and Captain Moses on the T-46 implementation program, such an analysis could verify the ability of ATC to satisfy Air Force training requirements during the transition period.

(d) A more detailed sensitivity analysis, incorporating the analysis of combinations of two or more factors, could be applied to the factorial experiment and the sensitivity analysis of this study to assess the impact of the interaction effects between significant factors. In this study, no sensitivity analysis was conducted on the interaction effects. Therefore, the results of the independent sensitivity analysis must be considered in light of this fact. An analysis of the interaction effects is easily done and would further refine the results of this analysis

Summary

As mentioned at the beginning of this section, the analysts found that the current system design can adequately satisfy the pilot training requirements of the Air Force and the Air Training Command. The factorial experiment and the sensitivity analysis were used to determine which variables in the system had a significant impact on system operation and at what levels do these variables become significant. Recommendations for future study were suggested to investigate those areas which, given the scope of this analysis, were not adequately covered and which are of interest to ATC and the Air Force.

Bibliography

1. Anderson, Ralph L., et al. <u>Multi-Track Undergraduate Pilot Training: An Analysis.</u> Air Command and Staff College Research Study, Maxwell AFB, AL, 1975.

2. Banks, Jerry and John S. Carson II, <u>Discrete-Event System Simulation</u>, Englewood Cliffs, N.J.: Prentice-Hall, 1984.

3. Charles, William M., Jr., Brig. General. "Pilot Training, 1986 and Beyond," <u>Air Force Magazine,</u> <u>65</u>: 42-47 (Feb 82).

4. Dickinson, Jack R., Jr., Major and Capt Glenn E. Moses. <u>An Analysis of the Implementation Plan for the Conversion from the T-37 to the T-46 Aircraft in Undergraduate Pilot Training.</u> MS Thesis, AFIT/GST/OS/84M-8. School of Engineering, Air Force Institute of Technology (AU), Wright-Patterson AFB, OH, March 1984.

5. Gordon, Geoffrey, <u>Systems Simulation</u>, 2nd ed., Prentice-Hall, 1978.

6. <u>History of the Air Training Command: July 1952 - December 1952. Vol. 1:</u> USAF Archives. Maxwell AFB, AL, 1952.

7. <u>History of the Air Training Command: January 1955 - June 1955. Vol. 2:</u> USAF Archives. Maxwell AFB, AL, 1955.

8. Lilliefors, Hubert W., "On the Kolmogorov-Smirnov Test For Normality with Mean and Variance Unknown," <u>Journal of the American Statistical Association,</u> <u>62</u>: 399-402, (June 1967)

9. Montgomery, Douglas C., <u>Design and Analysis of Experiments,</u> 2nd ed., New York: John Wiley and Sons, 1984.

10. Myers, Raymond H., <u>Response Surface Methodology</u>, Virginia Polytechnic Institute and State University, 1976.

11. Pritsker, A. Alan B. and Claude Dennis Pegden, <u>Introduction to Simulation and SLAM</u>, New York: John Wiley and Sons, 1979.

12. Shannon, Robert E., <u>Systems Simulation: The Art and Science</u>, Englewood Cliffs, N.J.: Prentice-Hall, 1983.

13. <u>System Operational Concept For The Tanker Transport Bomber Training System,</u> Air Training Command Document, ATC/XPQ. Randolph AFB, TX, November 1982.

14. Vrettos, John D. Specialized Undergraduate Pilot Training - Impact on Assignment Flexibility, Air Command and Staff College Research Study. Maxwell AFB, AL, May 1980.

15. -----. The Automated Training Capability System. HQ ATC/DOX, Randolph AFB TX, 1974.

Appendix A: <u>Output</u> <u>Data</u> <u>From</u> <u>Factorial</u> <u>and</u> <u>Sensitivity</u> <u>Analysis</u> <u>Runs</u>

<u>Output</u> <u>From</u> <u>Factorial</u> <u>Analysis</u> <u>Runs</u>:

L Prim	W Prim	R Prim	V Prim	C Prim	L Basc	W Basc	R Basc	V Basc	C Basc

(1)

L Prim	W Prim	R Prim	V Prim	C Prim	L Basc	W Basc	R Basc	V Basc	C Basc
90.03	94.86	88.37	89.44	89.56	206.45	206.65	221.85	219.80	224.45
90.43	91.41	88.28	89.21	90.61	206.30	206.95	222.90	218.70	224.70
91.23	92.29	88.56	88.97	90.10	206.80	206.30	223.25	219.20	224.15

AE

119.70	124.65	91.42	93.03	94.42	209.20	209.25	222.15	217.65	224.50
117.35	127.85	91.68	93.78	96.69	210.25	211.10	222.05	218.35	224.30
115.95	122.75	92.89	92.64	95.77	208.20	207.95	222.35	219.20	223.85

BEF

90.50	93.98	88.98	88.40	90.20	207.75	207.40	221.05	220.50	224.70
90.49	92.41	88.20	89.07	89.93	208.20	207.95	220.95	219.50	224.90
90.51	91.93	88.12	88.72	89.90	208.25	207.60	223.15	219.05	224.80

CEF

91.67	100.36	88.73	89.55	91.42	206.80	205.80	221.80	220.35	223.20
91.49	92.73	88.85	90.23	90.44	207.95	206.95	220.70	220.60	224.05
90.95	96.80	88.44	90.56	91.07	207.05	206.30	222.65	219.45	223.45

DF

131.60	138.15	120.60	123.60	139.50	207.80	208.55	222.95	216.85	224.45
141.05	176.65	117.60	127.55	124.55	208.70	210.60	218.10	223.40	224.45
131.05	151.50	110.56	126.35	136.25	208.40	209.55	221.35	216.60	225.05

ABF

124.05	117.25	92.56	93.57	95.37	216.30	216.35	221.90	219.10	225.55
127.90	122.85	91.80	93.41	94.03	215.30	215.20	222.60	218.45	225.55
119.70	122.85	91.62	93.67	103.23	217.30	215.30	223.80	216.85	225.35

ACF

121.25	122.90	92.41	96.54	100.10	209.50	209.50	222.20	220.35	225.90
120.15	124.40	92.66	95.22	97.47	208.20	208.85	220.15	221.50	223.55
116.20	126.00	93.42	97.21	106.75	209.30	210.20	220.25	222.05	224.80

ADEF

144.25	162.40	147.10	137.45	161.20	214.05	214.30	220.60	221.70	224.10
113.80	153.80	139.55	147.55	139.90	212.45	212.10	219.45	223.55	224.35
151.55	143.25	142.45	143.00	133.00	216.40	214.45	219.20	224.65	223.95

** NOTE: Each row of data represents one replication of the model. The data represent the mean number of days to complete the respective training phase.

Output From Factorial Analysis Runs (Contd):

L Prim	W Prim	R Prim	V Prim	C Prim	L Basc	W Basc	R Basc	V Basc	C Basc

BC

91.67	91.65	88.57	89.17	90.33	207.95	209.10	223.20	216.30	223.65
91.10	92.64	88.96	89.94	91.01	208.50	208.85	224.00	218.75	224.25
91.44	91.52	88.69	89.57	90.78	207.35	207.45	222.30	219.75	223.85

BDE

150.00	138.80	115.40	125.20	123.10	209.90	210.75	219.95	221.35	224.25
145.25	158.40	111.25	123.60	126.50	208.45	209.10	221.35	216.40	223.60
134.25	159.90	117.90	126.10	111.05	209.20	209.20	220.80	219.90	223.80

CDE

148.35	159.00	106.03	122.65	127.10	210.00	210.05	221.85	219.50	223.85
128.95	171.80	98.68	122.00	126.00	208.10	209.05	218.25	221.85	223.75
139.80	171.35	123.65	119.00	137.85	208.45	208.55	218.70	219.65	223.50

ABCE

119.90	127.00	91.97	96.04	101.36	213.35	213.35	223.65	219.95	225.05
116.75	122.85	92.08	101.02	96.36	215.40	215.55	221.80	220.60	225.20
125.60	128.50	91.68	93.38	103.89	212.55	213.00	222.40	220.30	224.80

ABD

147.90	145.35	136.20	149.90	169.60	210.75	211.65	212.65	221.45	223.95
145.85	156.65	143.70	150.90	148.05	214.25	215.45	220.30	226.40	223.10
141.60	123.70	132.60	151.05	148.20	212.50	217.10	216.35	225.40	221.10

ACD

103.80	118.60	141.10	146.15	162.10	211.80	213.75	220.95	218.65	226.65
149.30	158.10	136.95	128.50	140.90	211.50	215.90	221.90	219.80	226.45
145.10	159.20	143.75	148.45	136.30	210.80	212.15	223.40	220.00	223.70

BCDF

142.95	145.20	107.90	122.25	124.05	209.80	209.65	219.40	219.30	222.70
144.50	160.95	119.70	128.80	125.45	209.10	210.00	218.25	222.25	224.40
126.75	148.45	108.00	127.60	123.60	209.45	210.05	219.80	222.75	224.70

ABCDEF

139.30	167.30	136.80	144.00	150.85	211.30	216.35	220.45	219.40	224.40
131.15	146.55	137.85	140.95	153.90	215.60	216.60	222.90	222.10	226.55
171.16	173.80	146.10	146.15	136.95	213.40	215.45	219.50	221.15	222.10

Output From Sensitivity Analysis Runs:

ANOVA For Various Production Goals:

1910 Goal	215.840	215.910	215.940
2000 Goal	216.120	216.250	216.080
2100 Goal	216.460	216.310	216.310
2200 Goal	217.090	217.260	216.980

ANOVA For Various FAR/TTB Ratios:

40/60 Ratio	206.550	206.625	206.550
41/59 Ratio	207.275	206.450	207.050
43/57 Ratio	207.625	206.975	206.600
45/55 Ratio	207.775	208.750	207.250

ANOVA For Reduction of 1 and 2 Simulators:

Base Case	90.453	89.986	90.229
1 Sim Down	105.838	103.149	105.801
2 Sims Down	126.300	124.660	130.340

ANOVA For Various Attrition Levels:

Low Attrit	93.169	92.028	92.212
Normal Attrit	90.453	89.986	90.229
High Attrit	89.071	88.898	89.177

ANOVA For Various T-46 Maintenance Abort Rates:

Low Rate	90.316	89.652	90.452
Normal Rate	90.453	89.986	90.229
High Rate	89.819	89.603	90.341

ANOVA For Various TTB Maintenance Abort Rates:

Low Rate	222.083	220.933	222.017
Normal Rate	222.033	222.100	222.200
High Rate	221.733	221.700	221.983

** NOTE: Each data point represents one replication of the model. The data represent the mean number of days to complete the respective training phase.

Appendix B: Statistical Printouts

Resolution 3: Days to Complete T-46's at Laughlin

Source	SS	df	MS	F*	
Regression	10689.69	7	1527.098	20.55901	p = .0000
Error	1188.461	16	74.27878		
Total	11878.15	23			

R-Square = .8999   Adjusted R-Square = .8562

Effect	Beta	Std Error	t*	p
Mean	123.0863			
Goal, A	9.210417	1.759247	5.235432	.0001
Ratio, B	-4.530417	1.759247	-2.575203	.0203
T-46's, C	1.12375	1.759247	.6387678	.5320
T-46 Sims, D	18.39375	1.759247	10.45547	.0000
TTB's, E	.5145834	1.759247	.2925021	.7737
TTB Sims, F	-.21875	1.759247	-.124343	.9026
B x C	-.37625	1.759247	-.21387	.8334

Bartlett's test for homogeneity of variance:
Chi-square = 44.63178   df = 7   p = .0000
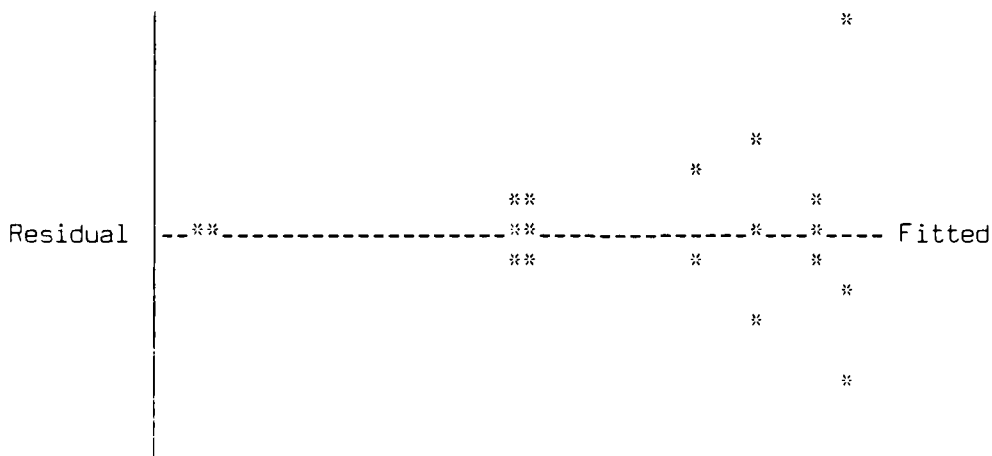
** NOTE: Refer to Page B-27 for a description of the
         statistical terms used in these printouts.

Resolution 3: Days to Complete T-46's at Williams

Source	SS	df	MS	F*
Regression	18232.62	7	2604.66	22.44397 p = .0000
Error	1856.826	16	116.0517	
Total	20089.44	23		

R-Square = .9076   Adjusted R-Square = .8671

Effect	Beta	Std Error	t*	p
Mean	132.6867			
Goal, A	5.805	2.198974	2.639868	.0178
Ratio, B	-10.39667	2.198974	-4.727964	.0002
T-46's, C	3.889167	2.198974	1.768628	.0960
T-46 Sims, D	24.13	2.198974	10.9733	.0000
TTB's, E	4.260834	2.198974	1.937646	.0705
TTB Sims, F	1.110833	2.198974	.5051599	.6203
B x C	1.064167	2.198974	.4839379	.6350

Bartlett's test for homogeneity of variance:
Chi-square = 25.67403   df = 7   p = .0006
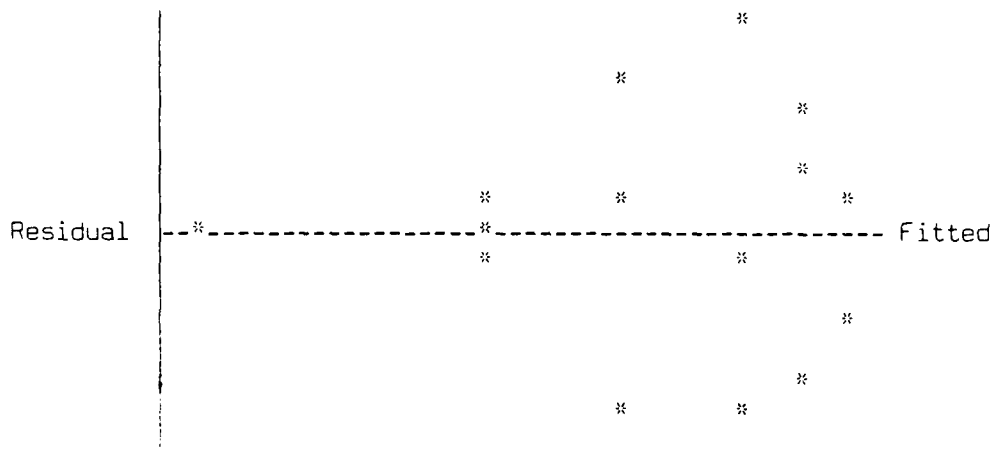
Resolution 3: Days to Complete T-46's at Reese

Source	SS	df	MS	F*	
Regression	9660.943	7	1380.135	44.09457	p = .0000
Error	500.7909	16	31.29943		
Total	10161.73	23			

R-Square = .9507   Adjusted R-Square = .9292

Effect	Beta	Std Error	t*	p
Mean	108.1821			
Goal, A	7.462084	1.141991	6.534277	.0000
Ratio, B	5.54875	1.141991	4.85884	.0002
T-46's, C	-.36375	1.141991	-.3185228	.7542
T-46 Sims, D	17.68208	1.141991	15.48356	.0000
TTB's, E	-.64875	1.141991	-.568087	.5779
TTB Sims, F	1.259583	1.141991	1.102972	.2864
B × C	1.127917	1.141991	.9876759	.3380

Bartlett's test for homogeneity of variance:
Chi-square = 31.86831   df = 7   p = .0000
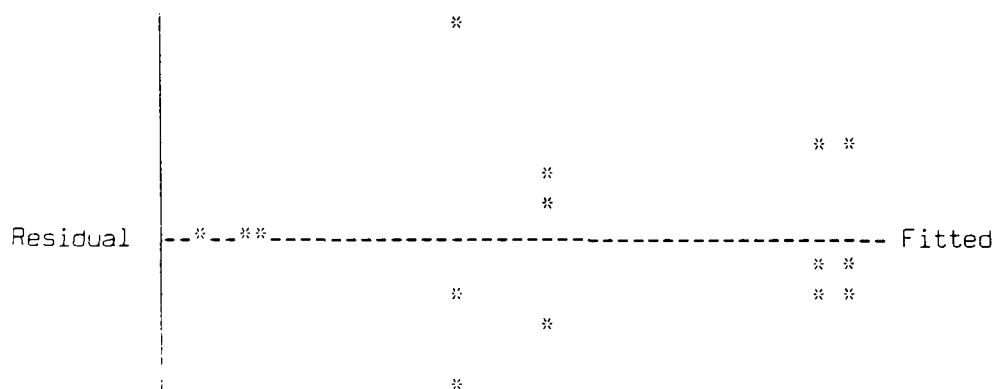
Resolution 4: Days to Complete SUPT at Williams

Source	SS	df	MS	F*	
Regression	470.5858	15	31.37239	22.23924	p = .0000
Error	45.14167	32	1.410677		
Total	515.7275	47			

R-Square = .9125   Adjusted R-Square = .8714

Effect	Beta	Std Error	t*	p
Mean	210.9011			
Goal, A	2.467708	.1714325	14.39463	.0000
Ratio, B	1.117708	.1714325	6.519816	.0000
T-46's, C	.034375	.1714325	.2005162	.8423
T-46 Sims, D	1.196875	.1714325	6.981611	.0000
TTB's, E	-.1447917	.1714325	-.8445986	.4046
TTB Sims, F	.1427083	.1714325	.8324462	.4113
A x B	.6260416	.1714325	3.651826	.0009
A x C	-.015625	.1714325	-.0911437	.9279
A x D	.0385417	.1714325	.2248212	.8235
B x C	.0635417	.1714325	.3706512	.7133
B x D	-.603125	.1714325	-3.518149	.0013
B x F	.1635417	.1714325	.9539711	.3472
D x E	.209375	.1714325	1.221326	.2309
A x B x D	-.3114583	.1714325	-1.816799	.0786
A x B x F	.246875	.1714325	1.440071	.1596

Bartlett's test for homogeneity of variance:
Chi-square = 21.40009   df = 15   p = .1245
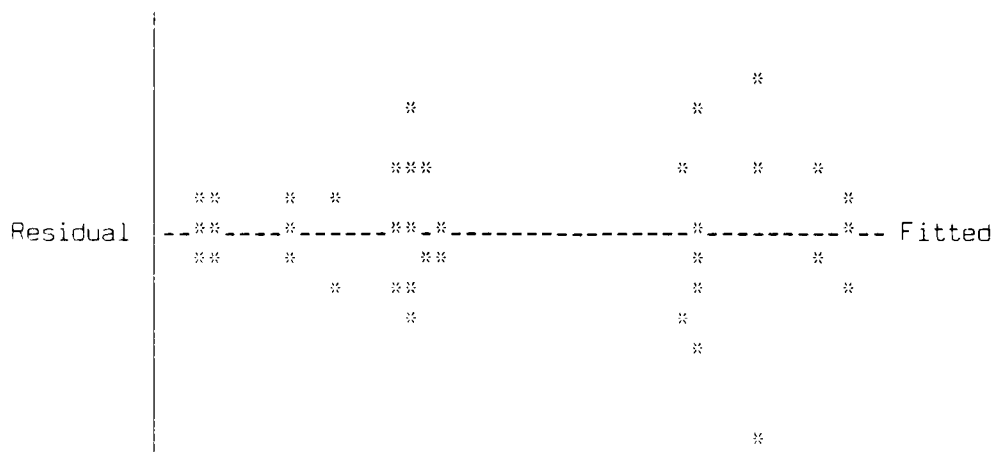
Resolution 4: Days to Complete SUPT at Laughlin

Source	SS	df	MS	F*	
Regression	374.4783	15	24.96522	20.67781	p = .0000
Error	38.635	32	1.207344		
Total	413.1133	47			

R-Square = .9065   Adjusted R-Square = .8626

Effect	Beta	Std Error	t*	p
Mean	210.3406			
Goal, A	2.144792	.158597	13.52354	.0000
Ratio, B	.9885417	.158597	6.233043	.0000
T-46's, C	-.2072917	.158597	-1.307034	.2005
T-46 Sims, D	.5822917	.158597	3.671518	.0009
TTB's, E	.1697917	.158597	1.070586	.2924
TTB Sims, F	.4239584	.158597	2.673181	.0117
A x B	.5260417	.158597	3.316846	.0023
A x C	-.3864583	.158597	-2.436732	.0206
A x D	-.1677083	.158597	-1.05745	.2982
B x C	.0239583	.158597	.1510643	.8809
B x D	-.7697917	.158597	-4.85376	.0000
B x F	.059375	.158597	.3743767	.7106
D x E	.3489584	.158597	2.200284	.0351
A x B x D	-.678125	.158597	-4.275776	.0002
A x B x F	.034375	.158597	.2167444	.8298

Bartlett's test for homogeneity of variance:
Chi-square = 20.23883   df = 15   p = .1630

B-16
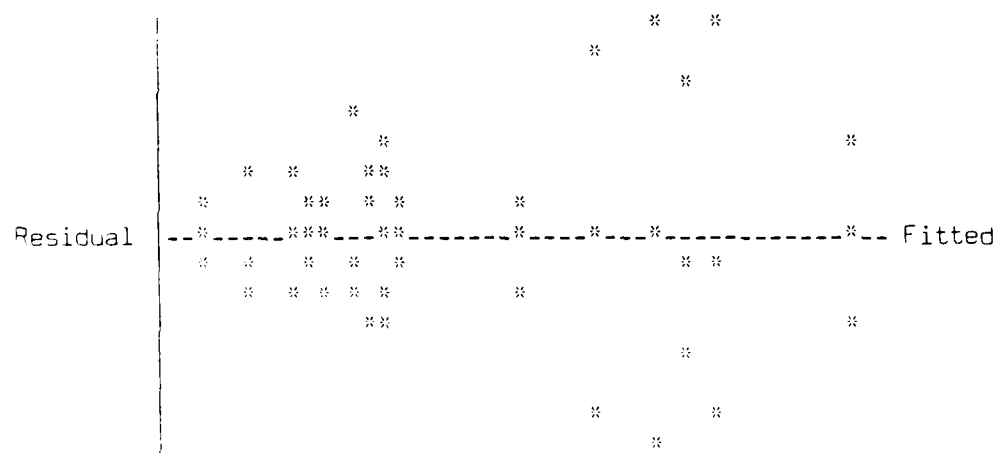
Resolution 4: Days to Complete T-46's at Columbus

```
Source       |    SS        df       MS          F*
-------------|-----------------------------------------------
Regression   |  26052.83    15    1736.855    31.70172    p = .0000
Error        |   1753.197   32      54.78742
-------------|-----------------------------------------------
Total        |  27806.03    47
```

R-Square = .9369   Adjusted R-Square = .9074

```
Effect            Beta        Std Error          t*            p
------            ----        ---------          --            -
Mean            116.1821
Goal, A           7.4175      1.068365        6.94285        .0000
Ratio, B          -.445       1.068365        -.4165242      .6798
T-46's, C          .3191667   1.068365         .298743       .7671
T-46 Sims, D      21.56584    1.068365       20.18582        .0000
TTB's, E          -1.23       1.068365       -1.151292       .2581
TTB Sims, F        .0308333   1.068365         .0288603      .9772
A x B              1.994583   1.068365        1.866949       .0711
A x C             -.0079167   1.068365        -.0074101      .9941
A x D              3.247084   1.068365        3.039301       .0047
B x C             -.3454167   1.068365        -.3233132      .7486
B x D             -.5279167   1.068365        -.494135       .6246
B x F             -.9795833   1.068365        -.9168992      .3661
D x E             -.90125     1.068365        -.8435784      .4052
A x B x D          1.824167   1.068365        1.707437       .0974
A x B x F          -.9108334  1.068365        -.8525486      .4002
```

Bartlett's test for homogeneity of variance:
Chi-square = 52.88198   df = 15   p = .0000

```
                                              * *
                                                    *

                               *        *  *        *
                  *     *                            *
                        *           *           *
Residual  --**--*--*-----------------*--------------------------- Fitted
             * *     *                  *
             * *                        *           * *
                                                        *
                          *           *           * *
                                                  *
```

Resolution 4: Days to Complete T-46's at Vance

Source	SS	df	MS	F*	
Regression	24337.13	15	1622.475	· 136.2023	p = .0000
Error	381.1913	32	11.91225		
Total	24718.32	47			

R-Square = .9846   Adjusted R-Square = .9773

Effect	Beta	Std Error	t*	p
Mean	113.356			
Goal, A	6.375625	.4981685	12.79813	.00C0
Ratio, B	.913125	.4981685	1.832964	.0761
T-46's, C	-.2339583	.4981685	-.469637	.6418
T-46 Sims, D	21.17521	.4981685	42.50612	.0000
TTB's, E	-.6864584	.4981685	-1.377964	.1778
TTB Sims, F	.035625	.4981685	.071512	.9434
A x B	.5252084	.4981685	1.054279	.2997
A x C	-.0302083	.4981685	-.0606388	.9520
A x D	3.597292	.4981685	7.221035	.0000
B x C	.0372917	.4981685	.0748575	.9408
B x D	.930625	.4981685	1.868093	.0709
B x F	-1.255625	.4981685	-2.520483	.0169
D x E	-.7072917	.4981685	-1.419784	.1653
A x B x D	.2852084	.4981685	.5725138	.5710
A x B x F	-.6177083	.4981685	-1.239959	.2240

Bartlett's test for homogeneity of variance:
Chi-square = 60.59138   df = 15   p = .0000

B-14

Resolution 4: Days to Complete T-46's at Reese

Source	SS	df	MS	F*	
Regression	20514.51	15	1367.634	65.46645	p = .0000
Error	668.4995	32	20.89061		
Total	21183.01	47			

R-Square = .9684   Adjusted R-Square = .9536

Effect	Beta	Std Error	t*	p
Mean	108.5533			
Goal, A	7.719167	.6597129	11.7008	.0000
Ratio, B	-.3520833	.6597129	-.5336918	.5972
T-46's, C	-.5129167	.6597129	-.7774847	.4426
T-46 Sims, D	18.1725	.6597129	27.54608	.0000
TTB's, E	.0216667	.6597129	.0328426	.9740
TTB Sims, F	.6216667	.6597129	.9423292	.3531
A x B	-.4904167	.6597129	-.743379	.4627
A x C	.6379167	.6597129	.9669611	.3408
A x D	5.900833	.6597129	8.944548	.0000
B x C	.5033334	.6597129	.7629583	.4511
B x D	-.2570833	.6597129	-.3896898	.6993
B x F	-.6704166	.6597129	-1.016225	.3171
D x E	.1491667	.6597129	.2261085	.8226
A x B x D	-.37125	.6597129	-.5627449	.5775
A x B x F	.6245833	.6597129	.9467503	.3509

Bartlett's test for homogeneity of variance:
Chi-square = 68.71681   df = 15   p = .0000


B-13
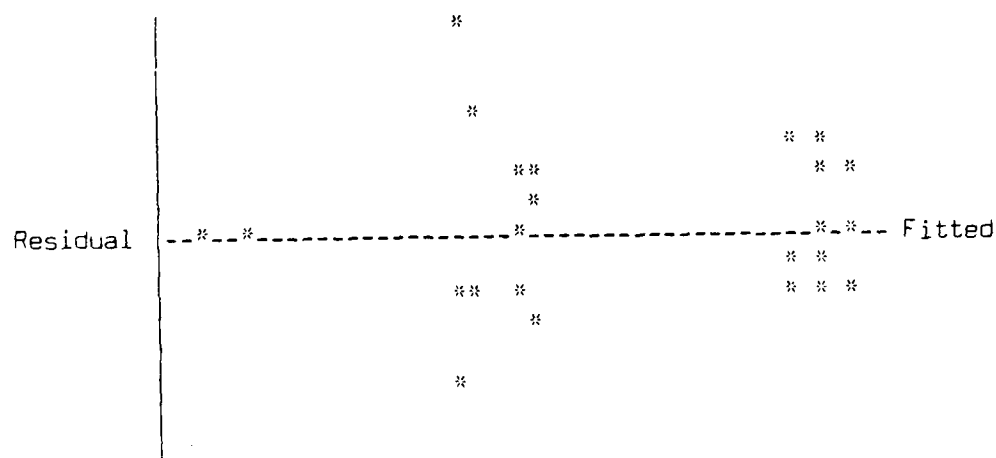
Resolution 4: Days to Complete T-46's at Williams

Source	SS	df	MS	F*	
Regression	31298.95	15	2086.597	18.54816	p = .0000
Error	3599.877	32	112.4962		
Total	34898.83	47			

R-Square = .8968   Adjusted R-Square = .8485

Effect	Beta	Std Error	t*	p
Mean	131.2767			
Goal, A	6.162917	1.530905	4.025669	.0003
Ratio, B	-1.256667	1.530905	-.8208653	.4178
T-46's, C	1.95875	1.530905	1.279472	.2099
T-46 Sims, D	22.42542	1.530905	14.64847	.0000
TTB's, E	3.23	1.530905	2.109863	.0428
TTB Sims, F	.9091667	1.530905	.5938754	.5568
A x B	1.704583	1.530905	1.113448	.2738
A x C	.2016667	1.530905	.1317304	.8960
A x D	-9.140001	1.530905	-5.970325	.0000
B x C	1.055417	1.530905	.6894071	.4955
B x D	-.3579167	1.530905	-.2337942	.8166
B x F	1.030833	1.530905	.673349	.5056
D x E	1.930417	1.530905	1.260965	.2164
A x B x D	1.41	1.530905	.9210239	.3639
A x B x F	.00875	1.530905	.0057156	.9955

Bartlett's test for homogeneity of variance:
Chi-square = 41.56912   df = 15   p = .0003
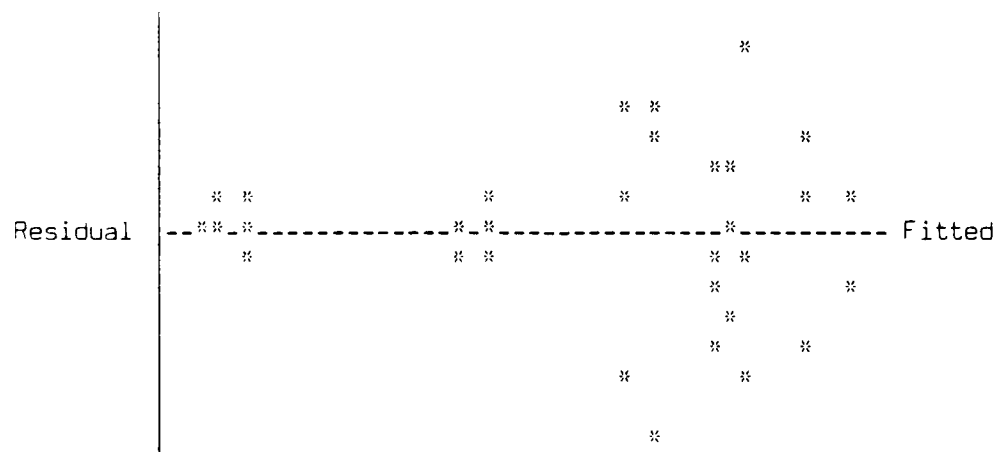
Resolution 4: Days to Complete T-46's at Laughlin

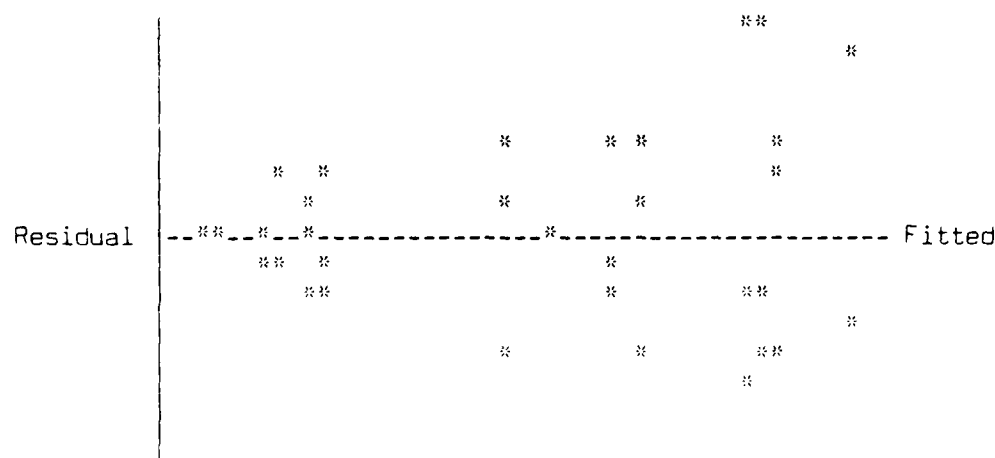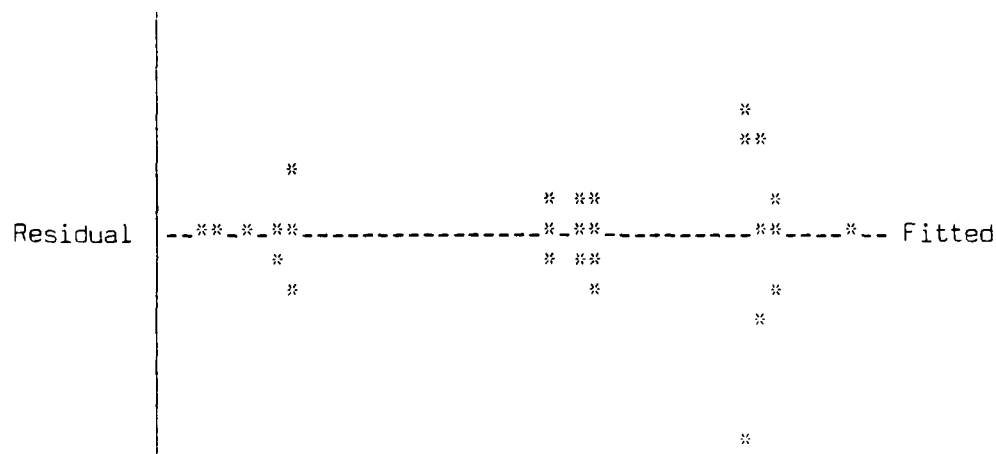| Source	SS	df	MS	F*	
Regression	19592.63	15	1306.175	11.44007	p = .0000
Error	3653.616	32	114.1755		
Total	23246.25	47			

R-Square = .8428   Adjusted R-Square = .7692

Effect	Beta	Std Error	t*	p
Mean	122.6098			
Goal, A	7.776042	1.542289	5.041883	.0000
Ratio, B	2.401458	1.542289	1.557074	.1293
T-46's, C	-.1397917	1.542289	-.0906391	.9283
T-46 Sims, D	16.94271	1.542289	10.98543	.0000
TTB's, E	.668125	1.542289	.4332035	.6678
TTB Sims, F	.055625	1.542289	.0360665	.9715
A x B	1.451042	1.542289	.9408362	.3538
A x C	-.274375	1.542289	-.1779011	.8599
A x D	-6.931875	1.542289	-4.494537	.0001
B x C	-.515625	1.542289	-.3343245	.7403
B x D	1.434375	1.542289	.9300298	.3593
B x F	-.1535417	1.542289	-.0995544	.9213
D x E	1.263542	1.542289	.8192638	.4187
A x B x D	.4764584	1.542289	.3089293	.7594
A x B x F	.139375	1.542289	.0903689	.9286

Bartlett's test for homogeneity of variance:
Chi-square = 74.37396   df = 15   p = .0000

B-11
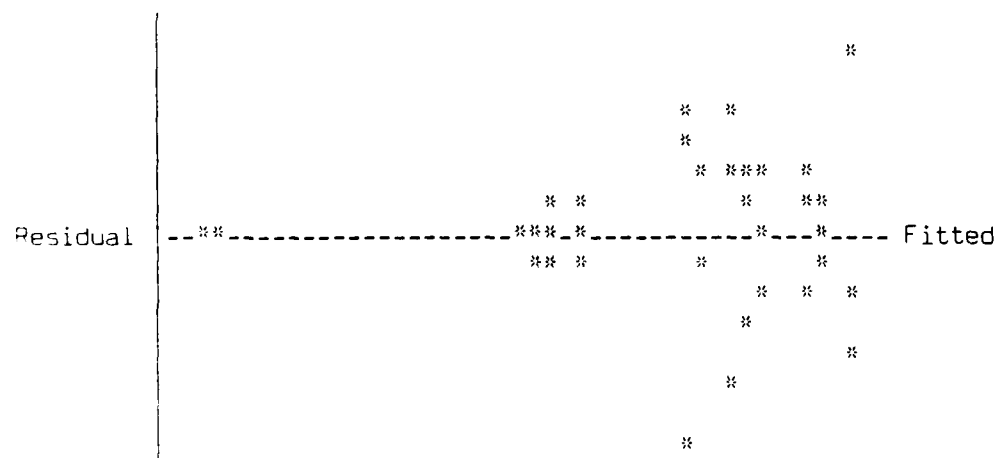
Resolution 3: Days to Complete SUPT at Columbus

Source	SS	df	MS	F*	
Regression	10.16125	7	1.451607	1.3133	p = .3061
Error	17.685	16	1.105313		
Total	27.84625	23			

R-Square = .3649   Adjusted R-Square = .0871

Effect	Beta	Std Error	t*	p
Mean	224.1375			
Goal, A	-.1291667	.2146036	-.601885	.5557
Ratio, B	-.1916667	.2146036	-.8931197	.3850
T-46's, C	.0416667	.2146036	.1941565	.8485
T-46 Sims, D	-.2833333	.2146036	-1.320264	.2053
TTB's, E	.1291667	.2146036	.601885	.5557
TTB Sims, F	.5	.2146036	2.329878	.0332
B x C	.1458333	.2146036	.6795476	.5065

Bartlett's test for homogeneity of variance:
Chi-square = 21.62422   df = 7   p = .0030
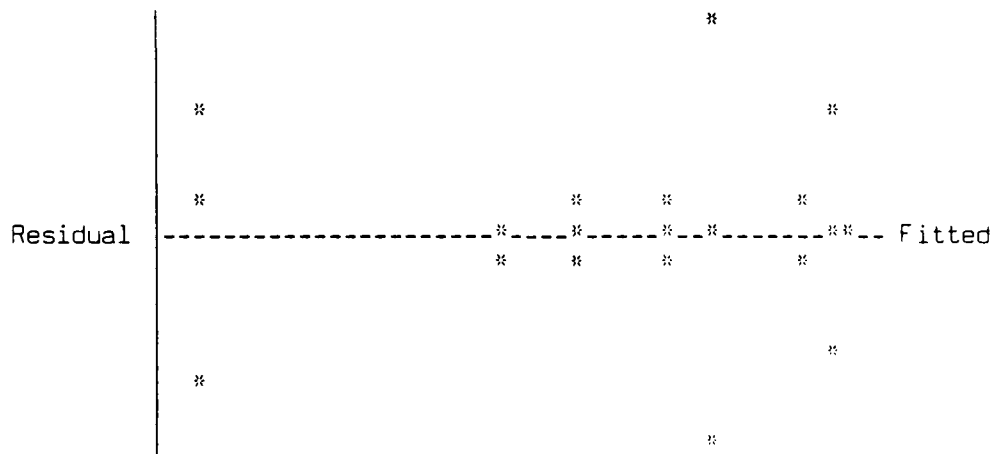
Resolution 3: Days to Complete SUPT at Vance

Source	SS	df	MS	F*	
Regression	84.69625	7	12.09947	3.185991	p = .0260
Error	60.76333	16	3.797708		
Total	145.4596	23			

R-Square = .5823   Adjusted R-Square = .3995

Effect	Beta	Std Error	t*	p
Mean	220.2792			
Goal, A	.9708334	.3977912	2.44056	.0267
Ratio, B	.5333334	.3977912	1.340737	.1987
T-46's, C	-.0833333	.3977912	-.2094901	.8367
T-46 Sims, D	.8666667	.3977912	2.178697	.0447
TTB's, E	-.4541667	.3977912	-1.141721	.2704
TTB Sims, F	-.075	.3977912	-.1885411	.8528
B x C	-1.154167	.3977912	-2.901439	.0104

Bartlett's test for homogeneity of variance:
Chi-square = 8.612528   df = 7   p = .2817
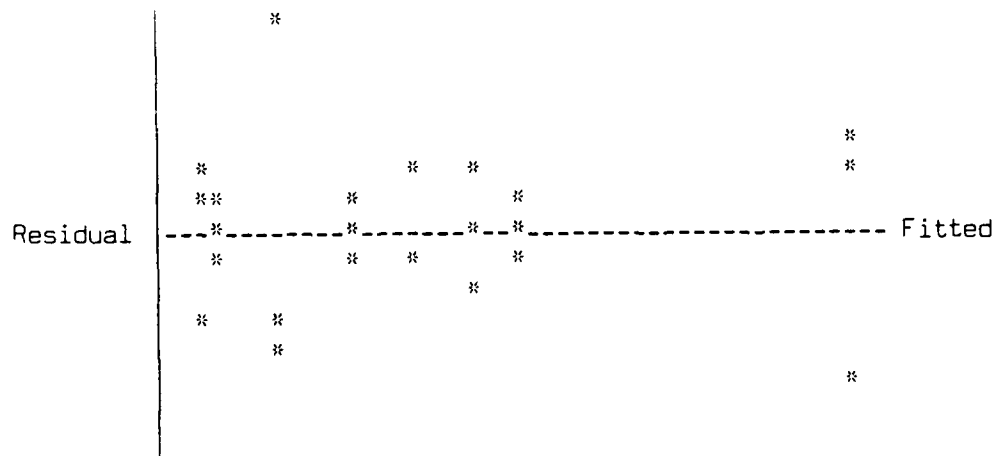
Resolution 3: Days to Complete SUPT at Reese

Source	SS	df	MS	F*	
Regression	86.49406	7	12.3563	3.158747	p = .0269
Error	62.58834	16	3.911771		
Total	149.0824	23			

R-Square = .5802   Adjusted R-Square = .3965

Effect	Beta	Std Error	t*	p
Mean	220.7146			
Goal, A	-.60625	.4037207	-1.501657	.1527
Ratio, B	-.1479167	.4037207	-.3663836	.7189
T-46's, C	.43125	.4037207	1.068189	.3013
T-46 Sims, D	-1.26875	.4037207	-3.142643	.0063
TTB's, E	.3979167	.4037207	.9856236	.3390
TTB Sims, F	.36875	.4037207	.9133789	.3746
B x C	1.060417	.4037207	2.626609	.0183

Bartlett's test for homogeneity of variance:
Chi-square = 12.30433   df = 7   p = .0910
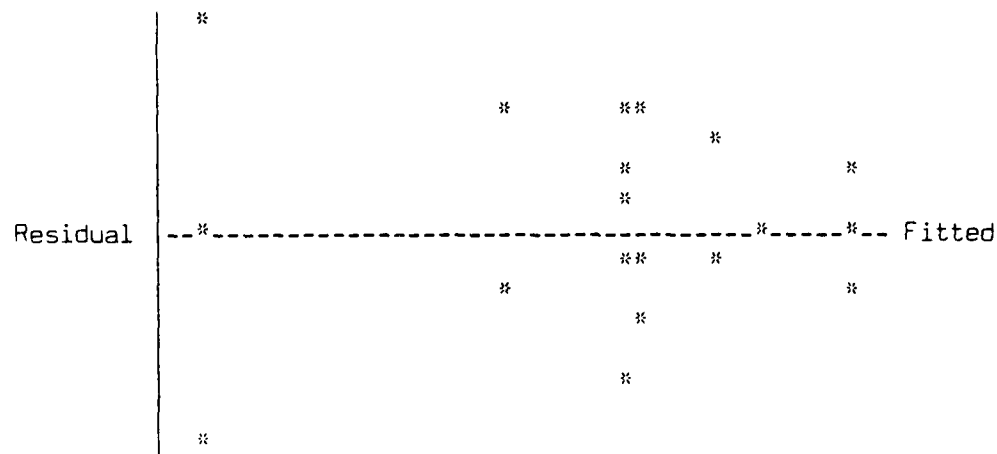
Resolution 3: Days to Complete SUPT at Williams

Source	SS	df	MS	F*	
Regression	199.4132	7	28.48761	16.70725	p = .0000
Error	27.28167	16	1.705104		
Total	226.6949	23			

R-Square = .8797   Adjusted R-Square = .8270

Effect	Beta	Std Error	t*	p
Mean	210.5896			
Goal, A	1.864583	.2665446	6.99539	.0000
Ratio, B	1.15625	.2665446	4.337924	.0005
T-46's, C	.24375	.2665446	.9144812	.3740
T-46 Sims, D	1.822917	.2665446	6.839069	.0000
TTB's, E	.01875	.2665446	.0703447	.9448
TTB Sims, F	.1270833	.2665446	.4767808	.6400
B × C .	.3104167	.2665446	1.164596	.2613

Bartlett's test for homogeneity of variance:
Chi-square = 10.72452   df = 7   p = .1511

B-7
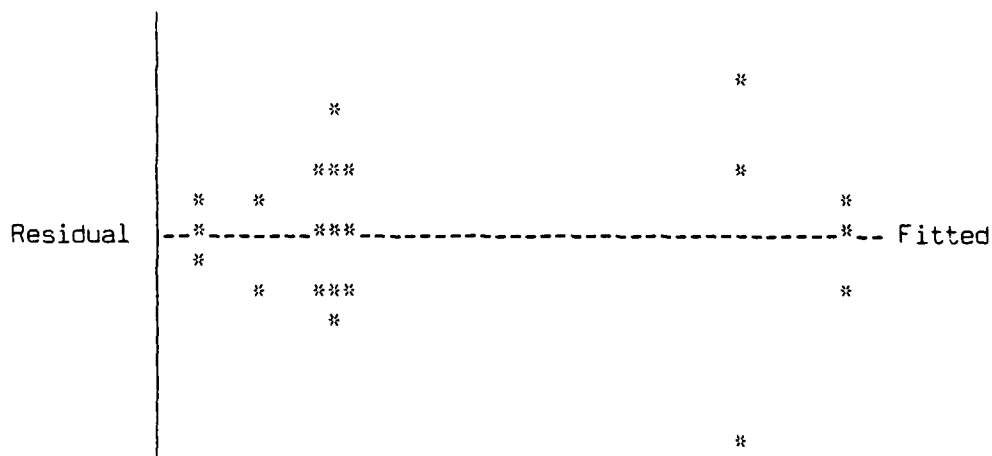
Resolution 3: Days to Complete SUPT at Laughlin

Source	SS	df	MS	F*	
Regression	92.88458	7	13.26923	9.769504	p = .0001
Error	21.73167	16	1.358229		
Total	114.6163	23			

R-Square = .8104   Adjusted R-Square = .7274

Effect	Beta	Std Error	t*	p
Mean	209.6625			
Goal, A	1.375	.2378926	5.77992	.0000
Ratio, B	.8208333	.2378926	3.450437	.0033
T-46's, C	.1416667	.2378926	.5955069	.5598
T-46 Sims, D	1.108333	.2378926	4.658966	.0003
TTB's, E	.2291667	.2378926	.9633199	.3497
TTB Sims, F	.0375	.2378926	.1576342	.8767
B x C	.0583333	.2378926	.2452087	.8094

Bartlett's test for homogeneity of variance:
Chi-square = 9.577539   df = 7   p = .2138
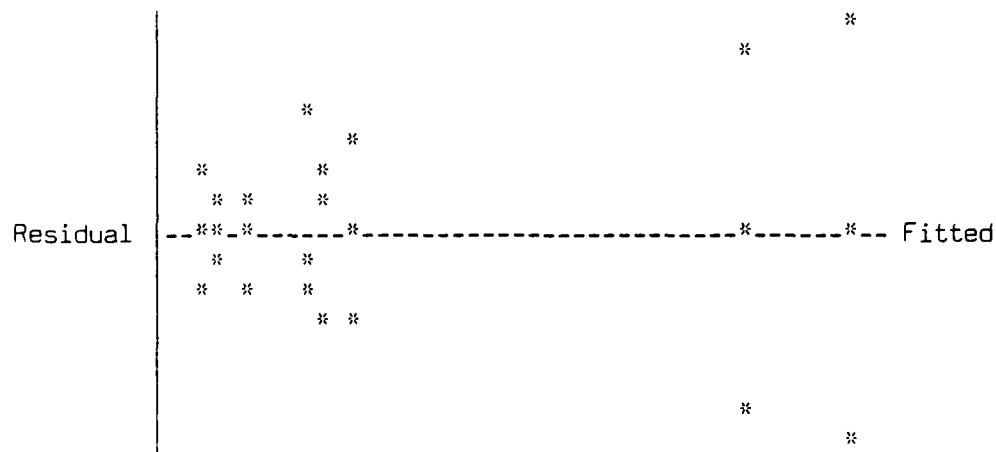
Resolution 3: Days to Complete T-46's at Columbus

Source	SS	df.	MS	F*	
Regression	14813.07	7	2116.152	46.45967	p = .0000
Error	728.7704	16	45.54815		
Total	15541.84	23			

R-Square = .9531   Adjusted R-Square = .9326

Effect	Beta	Std Error	t*	p
Mean	118.0063			
Goal, A	6.889583	1.377621	5.001074	.0001
Ratio, B	2.802083	1.377621	2.034002	.0589
T-46's, C	-.5820834	1.377621	-.422528	.6783
T-46 Sims, D	23.56042	1.377621	17.10225	.0000
TTB's, E	-2.209583	1.377621	-1.603913	.1283
TTB Sims, F	.0229167	1.377621	.016635	.9869
B × C	-1.25625	1.377621	-.9118981	.3754

Bartlett's test for homogeneity of variance:
Chi-square = 26.20519   df = 7   p = .0005
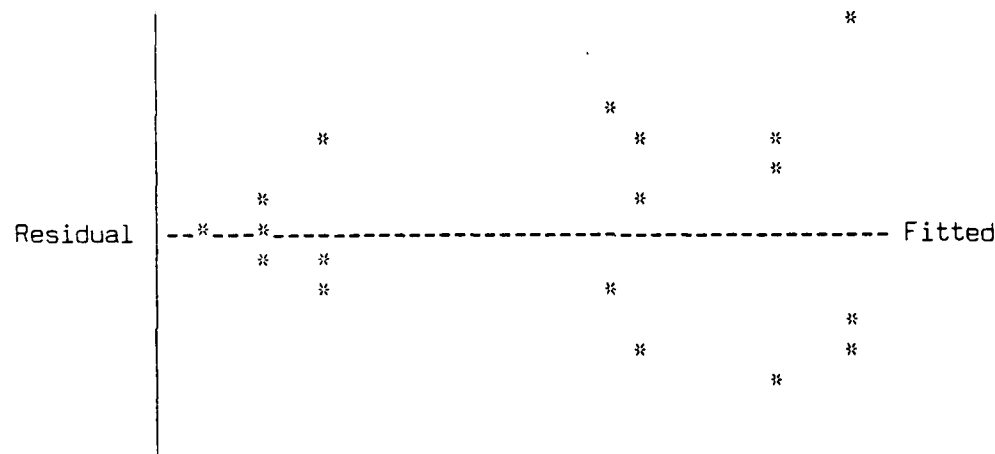
Resolution 3: Days to Complete T-46's at Vance

Source	SS	df	MS	F*	
Regression	13191.07	7	1884.438	901.0235	p = .0000
Error	33.46307	16	2.091442		
Total	13224.53	23			

R-Square = .9975   Adjusted R-Square = .9964

Effect	Beta	Std Error	t*	p
Mean	113.6413			
Goal, A	7.30625	.2952006	24.75012	.0000
Ratio, B	4.510417	.2952006	15.27916	.0000
T-46's, C	-.94125	.2952006	-3.18851	.0057
T-46 Sims, D	21.70042	.2952006	73.51075	.0000
TTB's, E	-1.942083	.2952006	-6.57886	.0000
TTB Sims, F	.0054167	.2952006	.0183491	.9856
B x C	-.5804167	.2952006	-1.966177	.0669

Bartlett's test for homogeneity of variance:
Chi-square = 12.36098   df = 7   p = .0893
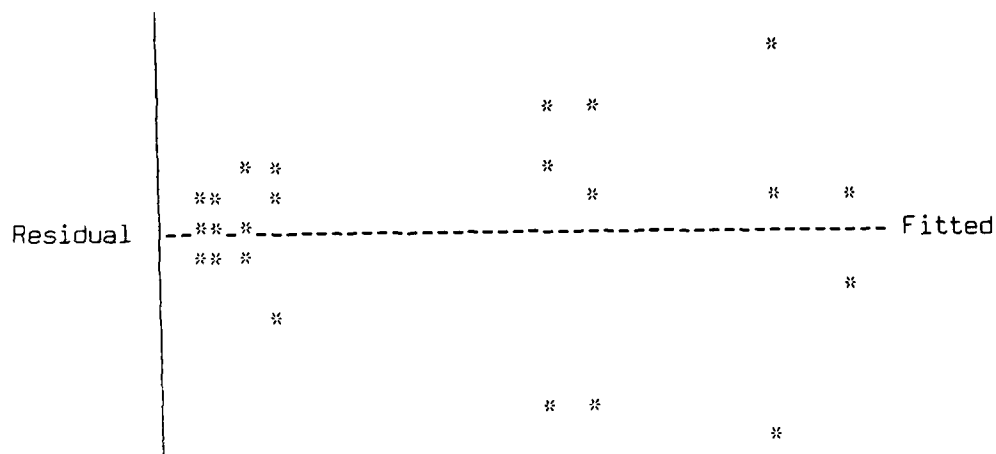
Resolution 4: Days to Complete SUPT at Reese

Source	SS	df	MS	F*	
Regression	134.0181	15	8.934542	3.779484	p = .0008
Error	75.64667	32	2.363958		
Total	209.6648	47			

R-Square = .6392   Adjusted R-Square = .4701

Effect	Beta	Std Error	t*	p
Mean	221.0729			
Goal, A	-.1166667	.2219215	-.5257116	.6027
Ratio, B	-.1354167	.2219215	-.6102009	.5460
T-46's, C	.1958333	.2219215	.8824444	.3841
T-46 Sims, D	-1.139583	.2219215	-5.135076	.0000
TTB's, E	.08125	.2219215	.3661206	.7167
TTB Sims, F	-.1083333	.2219215	-.4881608	.6288
A × B	-.1291667	.2219215	-.5820378	.5646
A × C	.4770834	.2219215	2.149785	.0392
A × D	-.0125	.2219215	-.0563262	.9554
B × C	.3375	.2219215	1.520809	.1381
B × D	-.4895834	.2219215	-2.206111	.0347
B × F	.3166667	.2219215	1.426931	.1633
D × E	.2354167	.2219215	1.060811	.2967
A × B × D	-.3583333	.2219215	-1.614686	.1162
A × B × F	.7229167	.2219215	3.257534	.0027

Bartlett's test for homogeneity of variance:
Chi-square = 20.94601   df = 15   p = .1386
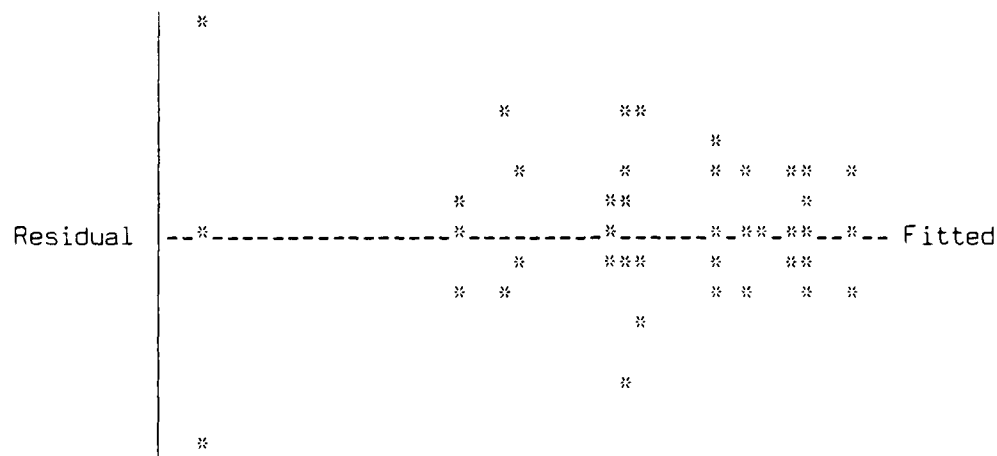
Resolution 4: Days to Complete SUPT at Vance

Source	SS	df	MS	F*	
Regression	138.3208	15	9.221385	3.264027	p = .0024
Error	90.405	32	2.825156		
Total	228.7258	47			

R-Square = .6047   Adjusted R-Square = .4195

Effect	Beta	Std Error	t*	p
Mean	220.2156			
Goal, A	.559375	.2426055	2.305698	.0278
Ratio, B	.0739583	.2426055	.3048502	.7625
T-46's, C	.0489583	.2426055	.2018023	.8413
T-46 Sims, D	.7864583	.2426055	3.241717	.0028
TTB's, E	.0635417	.2426055	.2619136	.7951
TTB Sims, F	.2614583	.2426055	1.07771	.2892
A x B	.0802083	.2426055	.3306122	.7431
A x C	-.3364583	.2426055	-1.386854	.1751
A x D	.459375	.2426055	1.893506	.0674
B x C	-.121875	.2426055	-.5023588	.6189
B x D	.4114584	.2426055	1.695998	.0996
B x F	-.5177084	.2426055	-2.133952	.0406
D x E	-.1322917	.2426055	-.5452955	.5893
A x B x D	.0635417	.2426055	.2619136	.7951
A x B x F	-1.032292	.2426055	-4.255022	.0002

Bartlett's test for homogeneity of variance:
Chi-square = 20.26607   df = 15   p = .1620
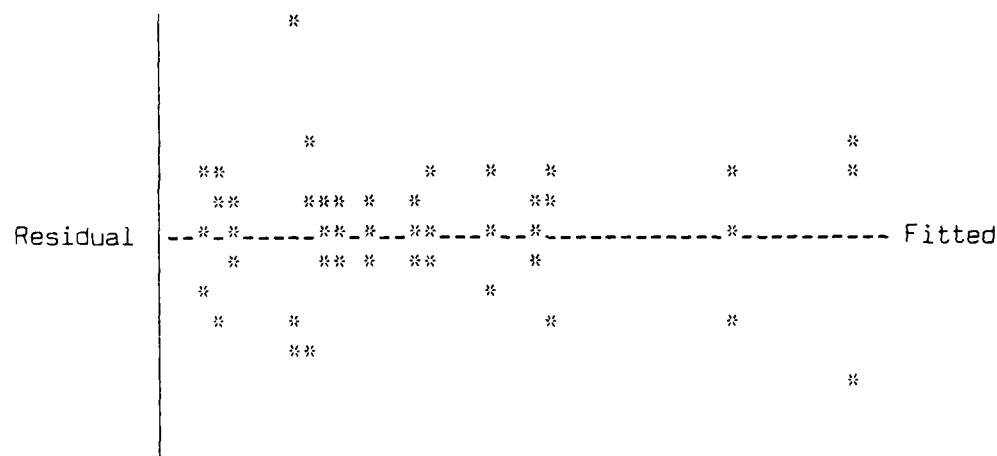
Resolution 4: Days to Complete SUPT at Columbus

Source	SS	df	MS	F*	
Regression	24.25787	15	1.617191	1.960851	p = .0540
Error	26.39167	32	.8247396		
Total	50.64953	47			

R-Square = .4789   Adjusted R-Square = .2347

Effect	Beta	Std Error	t*	p
Mean	224.3219			
Goal, A	.2114584	.1310804	1.613195	.1165
Ratio, B	-.059375	.1310804	-.4529662	.6536
T-46's, C	.0322917	.1310804	.24635	.8070
T-46 Sims, D	-.2010417	.1310804	-1.533728	.1349
TTB's, E	-.1135417	.1310804	-.8661986	.3928
TTB Sims, F	.1364583	.1310804	1.041028	.3057
A x B	-.0822917	.1310804	-.6277953	.5346
A x C	.3635417	.1310804	2.773425	.0092
A x D	-.1322917	.1310804	-1.009241	.3204
B x C	.009375	.1310804	.071521	.9434
B x D	-.340625	.1310804	-2.598596	.0140
B x F	.2427084	.1310804	1.851599	.0733
D x E	.009375	.1310804	.071521	.9434
A x B x D	-.184375	.1310804	-1.406579	.1692
A x B x F	.1364583	.1310804	1.041028	.3057

Bartlett's test for homogeneity of variance:
Chi-square = 42.39926   df = 15   p = .0002

B-20
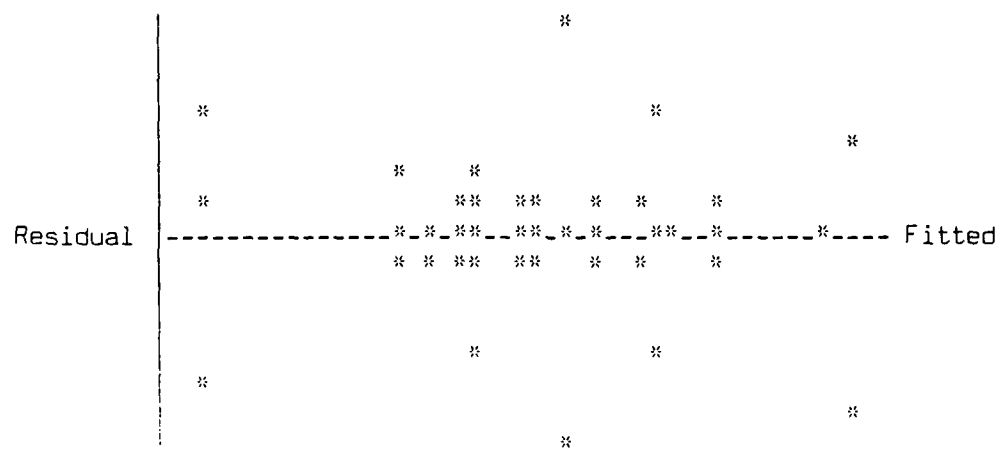
ANOVA for various Production Goals

Source	SS	df	MS	F*	
Regression	2.459425	3	.8198083	86.44728	p = .0000
Error	.0758667	8	.0094833		
Total	2.535292	11			

R-Square = .9701   Adjusted R-Square = .9589

Bartlett's test for homogeneity of variance:
Chi-square = 1.584687   df = 3   p = .6629
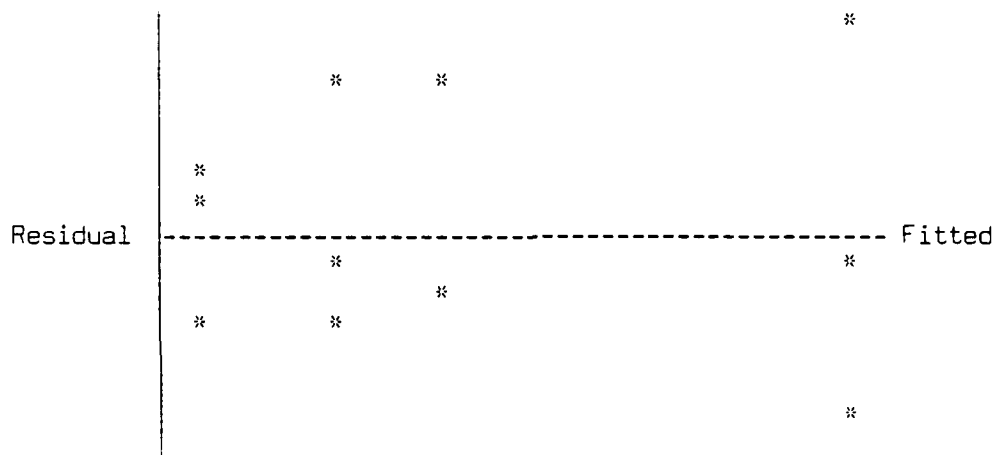
Duncan's Multiple Range Test (p=.05)

	Mean	Variance
1. 1910 Goal	215.8967	.0026333
2. 2000 Goal	216.15	.0079
3. 2100 Goal	216.36	.0075
4. 2200 Goal	217.11	.0199

Standard Error = .0562238   df = 8
4 vs. 1 : 1.213333 > .1950964 (R4) Reject equal
4 vs. 2 : .96 > .1905986 (R3) Reject equal
4 vs. 3 : .75 > .1832895 (R2) Reject equal
3 vs. 1 : .4633334 > .1905986 (R3) Reject equal
3 vs. 2 : .21 > .1832895 (R2) Reject equal
2 vs. 1 : .2533333 > .1832895 (R2) Reject equal

ANOVA for various FAR/TTB Ratios

Source	SS	df	MS	F*
Regression	2.957656	3	.9858854	3.820953 p = .0575
Error	2.064167	8	.2580209	
Total	5.021823	11		

R-Square = .5890   Adjusted R-Square = .4348

Bartlett's test for homogeneity of variance:
Chi-square = 7.322078   df = 3   p = .0623
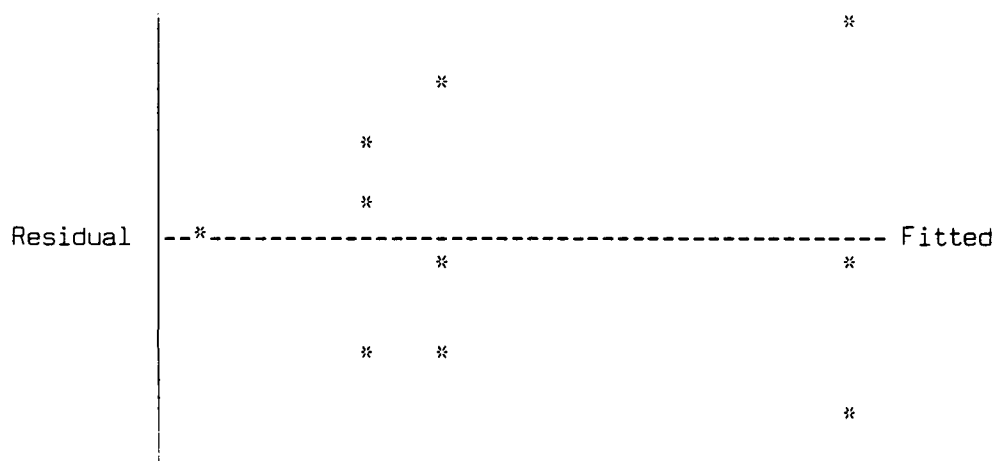
Duncan's Multiple Range Test (p=.05)

	Mean	Variance
1. 40/60 Ratio	206.575	.001875
2. 41/59 Ratio	206.925	.181875
3. 43/57 Ratio	207.0667	.2689583
4. 45/55 Ratio	207.925	.579375

Standard Error = .2932694   df = 8
4 vs. 1 : 1.35 > 1.017645 (R4) Reject equal
4 vs. 2 : 1 > .9941833 (R3) Reject equal
4 vs. 3 : .8583333 < .9560582 (R2) Do not reject equal
3 vs. 1 : .4916667 < .9941833 (R3) Do not reject equal
3 vs. 2 : .1416667 < .9560582 (R2) Do not reject equal
2 vs. 1 : .35 < .9560582 (R2) Do not reject equal

ANOVA for Reduction of 1 and 2 Simulators

Source	SS	df	MS	F*
Regression	2067.762	2	1033.881	282.5408 p = .0000
Error	21.95537	6	3.659228	
Total	2089.718	8		

R-Square = .9895   Adjusted R-Square = .9860

Bartlett's test for homogeneity of variance:
Chi-square = 6.200013   df = 2   p = .0450

```
                                                    *




                                 *

Residual  |--*-------------------------------------------- Fitted
            *
                                                *

                           *
                                                *


```
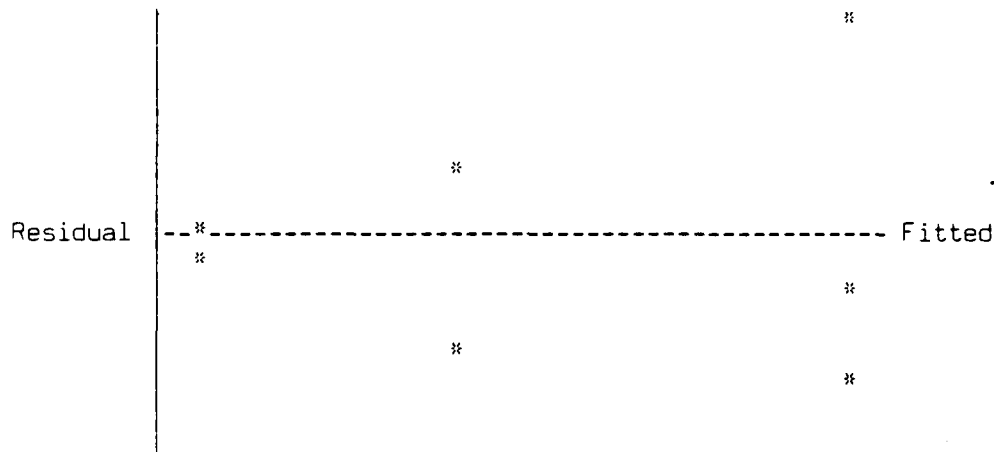
Duncan's Multiple Range Test (p=.05)

	Mean	Variance
1. Base case	90.22266	.0545523
2. 1 Sim Down	104.9293	2.377532
3. 2 Sims Down	127.1	8.5456

Standard Error = 1.10442   df = 6
3 vs. 1 : 36.87734 > 3.953822 (R3) Reject equal
3 vs. 2 : 22.17067 > 3.821292 (R2) Reject equal
2 vs. 1 : 14.70667 > 3.821292 (R2) Reject equal

ANOVA for various Attrition Levels

Source	SS	df	MS	F*	
Regression	18.13053	2	9.065262	60.482	p = .0001
Error	.899302	6	.1498837		
Total	19.02983	8			

R-Square = .9527   Adjusted R-Square = .9370

Bartlett's test for homogeneity of variance:
Chi-square = 3.461541   df = 2   p = .1771

```
                                                                *
                          |
                          |
                          |
                          |
                          |                *
              *           |
Residual      |--*-------------------*---------------------------- Fitted
              |
              |   *                   *
              |                                          *
              |                                          *
              |
              |
              |
```
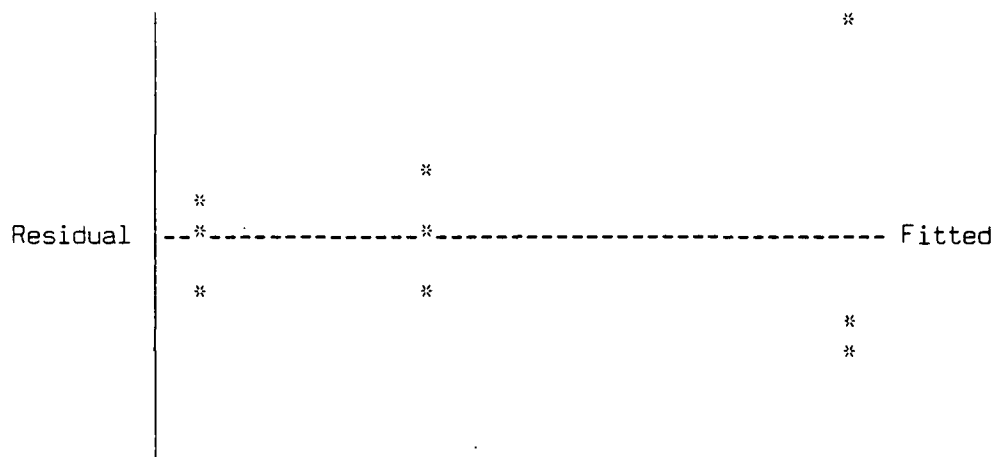
Duncan's Multiple Range Test (p=.05)

	Mean	Variance
1. Low Attrit	92.46966	.3752644
2. Normal Attrit	90.22266	.0545523
3. High Attrit	89.04867	.0198343

Standard Error = .2235201   df = 6
1 vs. 3 : 3.421 > .8002018 (R3) Reject equal
1 vs. 2 : 2.247 > .7733795 (R2) Reject equal
2 vs. 3 : 1.174 > .7733795 (R2) Reject equal

ANOVA for various T-46 Maintenance Abort Rates

Source	SS	df	MS	F*	
Regression	.1457976	2	.0728988	.572881	p = .5920
Error	.7634966	6	.1272495		
Total	.9092942	8			

R-Square = .1603   Adjusted R-Square = .0000

Bartlett's test for homogeneity of variance:
Chi-square = .5874103   df = 2   p = .7455

```
           |
           |  *
           |
           |
           |                                    *
           |                                    *              *
           |
  Residual |----------------------------------------------*-- Fitted
           |  *
           |
           |                                              *
           |
           |  *
           |
           |                           *
```
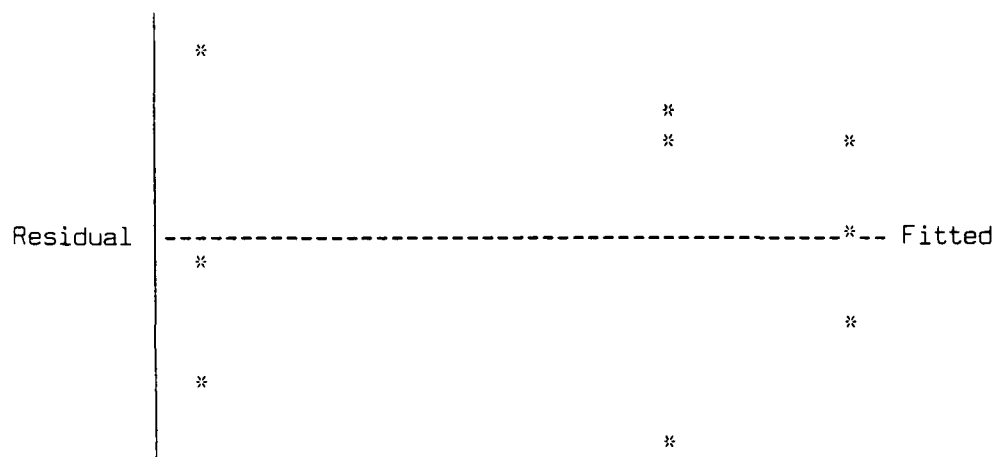
Duncan's Multiple Range Test (p=.05)

	Mean	Variance
1. Low Rate	90.14	.183232
2. Normal Rate	90.22266	.0545523
3. High Rate	89.921	.143964

Standard Error = .2059526   df = 6
2 vs. 3 : .3016667 < .7373104 (R3) Do not reject equal
2 vs. 1 : .0826667 < .7125961 (R2) Do not reject equal
1 vs. 3 : .219 < .7125961 (R2) Do not reject equal

ANOVA for various TTB Maintenance Abort Rates

Source	SS	df	MS	F*	
Regression	.2975087	2	.1487543	.9961346	p = .4231
Error	.8959894	6	.1493316		
Total	1.193498	8			

R-Square = .2493   Adjusted R-Square = .0000

Bartlett's test for homogeneity of variance:
Chi-square = 6.307847   df = 2   p = .0427

```
             |
             |
             |
             |
          *  |
          *  |
             |          *
             |                                              *
Residual     |-----------------------------------------------*-- Fitted
             |          *                                    *
             |
             |
             |
             |
          *  |
             |
```
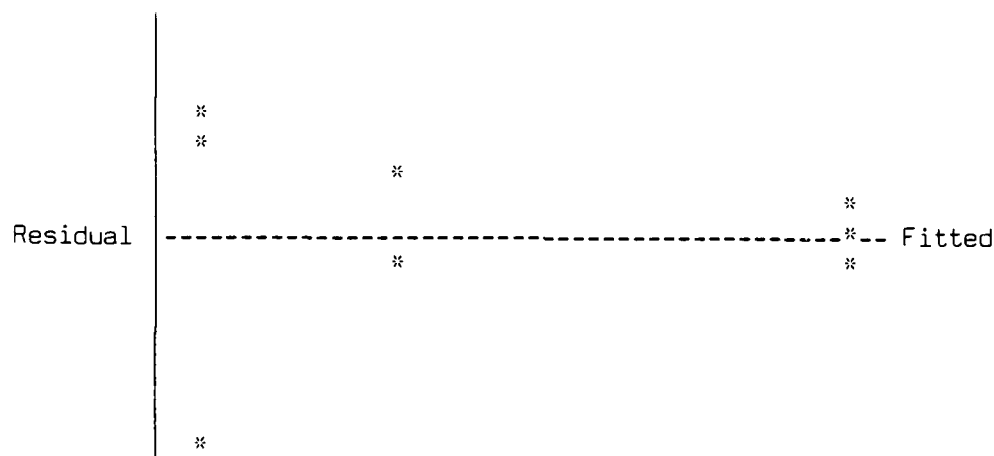
Duncan's Multiple Range Test (p=.05)

	Mean	Variance
1. Low Rate	221.6777	.4169853
2. Normal Rate	222.111	.007063
3. High Rate	221.8053	.0239463

Standard Error = .223108   df = 6
2 vs. 1 : .4333334 < .7987267 (R3) Do not reject equal
2 vs. 3 : .3056667 < .7719537 (R2) Do not reject equal
3 vs. 1 : .1276667 < .7719537 (R2) Do not reject equal

Description of Statistical Terms

SS - Sum of Squares

df - Degrees of freedom

MS - Mean Square (SS/df)

F^* - F statistic ($MS_{Regression}/MS_{Error}$)

p - Probability value. Indicates the level of significance of the
F^* statistic. This value represents the probability of
rejecting the null hypothesis when the null hypothesis is true.
The null hypothesis for this test is that all the Beta values,
the coefficients of the regression equation, are equal to zero.
The F test, as it is used here, determines whether there are
any significant factor and interaction effects.   A p - value
close to zero indicates that the Beta is not zero and that the
factor or interaction effect is significant.

R square - The proportion of variation explained by the statistical
          model.

Adjusted R square - The R square statistic adjusted for the number
                    of independent variables used.

Beta - *The regression coefficient.*

Std Error - The estimator of standard error for the respective
            regression coefficient. The estimator is equal to
            the product of the square root of the MS_{Error} and
            the corresponding term in the variance-covariance
            matrix (X transpose X inverse).

t^* - t statistic (Beta/Std Error)

p - Probability value. Used with t^*, the p - value indicates the
     level of significance for the t^* statistic.   The null
     hypothesis   for this test is that the particular   Beta
     coefficient is equal to zero.   This test determines whether
     the particular main effect or interaction is significant.   As
     with the F test, a p - value close to zero indicates that the
     effect is significant.

Chi square - The chi square statistic computed for Bartlett's Test.

p - Probability value. When used in Bartlett's Test, the p - value
     indicates   the   level   of significance of the chi square
     statistic. The null hypothesis tested here is that the
     variances for the different runs are equal. A p - value close
     to zero indicates that the variances are not equal.

Residual Plot - Plots the difference between individual observa-
                 tions and the overall mean, versus the fitted, or
                 predicted value for that observation.   A random
                 disperal of points suggests that the errors are
                 normally distributed.

Appendix C: SUPT Model (SLAM Code)

```
GEN,MIKE & JOE,SUPT,11/27/84,1,,N;
LIMITS,35,5,2500;
INTLC,XX(1)=.4;                     % OF STUDENTS TO FAR
INTLC,XX(2)=15;                     DAYS TO PCS
INTLC,XX(3)=16;                     INITIALIZE CLASS #
INTLC,XX(4)=30;                     LAUGHLIN T-46 STUDENTS/CLASS
INTLC,XX(5)=31;                     WILLIAMS T-46 STUDENTS/CLASS
INTLC,XX(6)=26;                     REESE T-46 STUDENTS/CLASS
INTLC,XX(7)=27;                     VANCE T-46 STUDENTS/CLASS
INTLC,XX(8)=29;                     COLUMBUS T-46 STUDENTS/CLASS
INTLC,XX(9)=24;                     LAUGHLIN T-38 STUDENTS/CLASS
INTLC,XX(10)=25;                    WILLIAMS T-38 STUDENTS/CLASS
INTLC,XX(11)=23;                    REESE TTB STUDENTS/CLASS
INTLC,XX(12)=25;                    VANCE TTB STUDENTS/CLASS
INTLC,XX(13)=26;                    COLUMBUS TTB STUDENTS/CLASS
INIT,240,615;
MONTR,CLEAR,480;
NETWORK;
        RESOURCE/T46A(55),6;        LAUGHLIN'S T-46'S
        RESOURCE/PRIIPA(160),7;     LAUGHLIN'S T-46 IP'S
        RESOURCE/T46SIMA(8),8;      LAUGHLIN'S T-46 SIMS
        RESOURCE/T38A(61),9;        LAUGHLIN'S T-38'S
        RESOURCE/BASIPA(172),10;    LAUGHLIN'S T-38 IP'S
        RESOURCE/T38SIMA(8),11;     LAUGHLIN'S T-38 SIMS
        RESOURCE/T46B(55),12;       WILLY'S T-46'S
        RESOURCE/PRIIPB(162),13;    WILLY'S T-46 IP'S
        RESOURCE/T46SIMB(8),14;     WILLY'S T-46 SIMS
        RESOURCE/T38B(62),15;       WILLY'S T-38'S
        RESOURCE/BASIPB(182),16;    WILLY'S T-38 IP'S
        RESOURCE/T38SIMB(8),17;     WILLY'S T-38 SIMS
        RESOURCE/T46C(53),18;       REESE'S T-46'S
        RESOURCE/PRIIPC(164),19;    REESE'S T-46 IP'S
        RESOURCE/T46SIMC(8),20;     REESE'S T-46 SIMS
        RESOURCE/TTBA(102),21;      REESE'S TTB'S
        RESOURCE/BASIPC(334),22;    REESE'S TTB IP'S
        RESOURCE/TTBSIMA(16),23;    REESE'S TTB SIMS
        RESOURCE/T46D(49),24;       VANCE'S T-46'S
        RESOURCE/PRIIPD(164),25;    VANCE'S T-46 IP'S
        RESOURCE/T46SIMD(8),26;     VANCE'S T-46 SIMS
        RESOURCE/TTBB(102),27;      VANCE'S TTB'S
        RESOURCE/BASIPD(306),28;    VANCE'S TTB IP'S
        RESOURCE/TTBSIMB(16),29;    VANCE'S TTB SIMS
        RESOURCE/T46E(54),30;       COLUMBUS' T-46'S
        RESOURCE/PRIIPE(165),31;    COLUMBUS' T-46 IP'S
        RESOURCE/T46SIME(8),32;     COLUMBUS' T-46 SIMS
        RESOURCE/TTBC(102),33;      COLUMBUS' TTB'S
        RESOURCE/BASIPE(334),34;    COLUMBUS' TTB IP'S
        RESOURCE/TTBSIMC(16),35;    COLUMBUS' TTB SIMS
```

```
          GATE/GTLAU,CLOSE,1;
          GATE/GTWIL,CLOSE,2;
          GATE/GTREE,CLOSE,3;
          GATE/GTVAN,CLOSE,4;
          GATE/GTCOL,CLOSE,5;
  ;
  ;  PRIMARY CLASS GENERATING ROUTINE
  ;
          CREATE,15,240;                    START NEW CLASS.
          OPEN,GTLAU;                       RELEASE LAUGHLIN FAR.
          OPEN,GTWIL;                       RELEASE WILLY FAR.
          OPEN,GTREE;  ·                    RELEASE REESE TTB.
          OPEN,GTVAN;                       RELEASE VANCE TTB.
          OPEN,GTCOL;                       RELEASE COLUMBUS TTB.
          ASSIGN,XX(3)=XX(3)+1,5;           INCREMENT CLASS NUMBER.
          ACT,,,FLT1;                       CREATE LAUGHLIN FLIGHT.
          ACT,,,FLT2;                       CREATE WILLIAMS FLIGHT.
          ACT,,,FLT3;                       CREATE REESE FLIGHT.
          ACT,,,FLT4;                       CREATE VANCE FLIGHT.
          ACT,,,FLT5;                       CREATE COLUMBUS FLIGHT.
  FLT1    ASSIGN,ATRIB(1)=ATRIB(1)+1,2;     GENERATE LAUGHLIN STUDENTS.
          ACT,,ATRIB(1).LT.XX(4),FLT1;      CONTINUE TO FILL FLIGHT.
          ACT;
          ASSIGN,ATRIB(1)=TNOW,
                 ATRIB(2)=XX(3);            MARK START DAY & CLASS #.
          ACT/1,,,DR1;                      SEND STUDENT TO LAUGHLIN.
  FLT2    ASSIGN,ATRIB(1)=ATRIB(1)+1,2;     GENERATE WILLIAMS STUDENTS.
          ACT,,ATRIB(1).LT.XX(5),FLT2;
          ACT;
          ASSIGN,ATRIB(1)=TNOW,
                 ATRIB(2)=XX(3);
          ACT/2,,,DR2;
  FLT3    ASSIGN,ATRIB(1)=ATRIB(1)+1,2;     GENERATE REESE STUDENTS.
          ACT,,ATRIB(1).LT.XX(6),FLT3;
          ACT;
          ASSIGN,ATRIB(1)=TNOW,
                 ATRIB(2)=XX(3);
          ACT/3,,,DR3;
  FLT4    ASSIGN,ATRIB(1)=ATRIB(1)+1,2;     GENERATE VANCE STUDENTS.
          ACT,,ATRIB(1).LT.XX(7),FLT4;
          ACT;
          ASSIGN,ATRIB(1)=TNOW,
                 ATRIB(2)=XX(3);
          ACT/4,,,DR4;
  FLT5    ASSIGN,ATRIB(1)=ATRIB(1)+1,2;     GENERATE COLUMBUS STUDENTS.
          ACT,,ATRIB(1).LT.XX(8),FLT5;
          ACT;
          ASSIGN,ATRIB(1)=TNOW,
                 ATRIB(2)=XX(3);
          ACT/5,,,DR5;
```

```
;
;   LAUGHLIN T-46 MODULE
;
DR1     ASSIGN,ATRIB(5)=USERF(1);                    DRAW ATTRITION RATE.
        ACT,37,,CNT1;                                PREFLIGHT AND ACADEMICS.
        ENTER,1;
CNT1    GOON,1;                                      CHECK REQUIREMENTS.
        ACT,,ATRIB(3).LT.68.AND.NNRSC(T46A).GE.1.AND.NNRSC(PRIIPA).GE.1,FLY1;
        ACT,,ATRIB(4).LT.27.AND.NNRSC(T46SIMA).GE.1.AND.NNRSC(PRIIPA).GE.1,SIM1;
        ACT,,ATRIB(3).GE.68.AND.ATRIB(4).GE.27,COL1;
        ACT,.33,,CNT1;
FLY1    ASSIGN,XX(86)=USERF(11),1;                   DRAW WX CNX RATE.
        ACT,,XX(86),WX1;                             WX CANCEL.
        ACT,,1-XX(86);                               VFR.
        AWAIT(7),PRIIPA;                             DRAW AN IP.
PLN1    AWAIT(6),T46A;                               DRAW AN A/C.
        ASSIGN,XX(14)=USERF(7),1;                    DRAW MNX CNX RATE.
        ACT,,XX(14),BRK1;                            MNX GROUND ABORT.
        ACT,.22,1-XX(14);                            GO FLY SORTIE.
        ASSIGN,ATRIB(3)=ATRIB(3)+1;                  INCREMENT SORTIE COUNT.
        FREE,T46A;                                   RELEASE A/C.
        ACT,.11;                                     DEBRIEF SORTIE.
        FREE,PRIIPA;                                 RELEASE IP.
        ASSIGN,XX(87)=USERF(2),1;                    ASSIGN ATTRITION.
        ACT,.17,1-XX(87),CNT1;                       CONTINUE STUDENT.
        ACT/6,,XX(87);                               WASHOUT STUDENT.
        TERM;                                        ADIOS, HAMFIST.
WX1     GOON,1;                                      SIM AVAILABLE?
        ACT,,ATRIB(4).LT.27.AND.NNRSC(T46SIMA).GE.1,SIM1;
        ACT,.33,,CNT1;                               TRY NEXT PERIOD.
BRK1    GOON,2;
        ACT,,,FIX1;                                  HAVE A/C REPAIRED.
        ACT,,NNRSC(T46A).GE.1,PLN1;                  TAKE SPARE A/C.
        ACT;                                         OTHERWISE
        FREE,PRIIPA;                                 RELEASE IP AND
        ACT,.33,,CNT1;                               TRY NEXT PERIOD.
FIX1    GOON;
        ACT,.12;                                     MX REPAIR TIME.
        FREE,T46A;                                   RELEASE A/C.
        TERM;
SIM1    AWAIT(7),PRIIPA;                             DRAW AN IP.
        AWAIT(8),T46SIMA;                            DRAW A SIM.
        ACT,.125;                                    SIM SESSION.
        ASSIGN,ATRIB(4)=ATRIB(4)+1;                  INCREMENT SIM COUNT.
        FREE,T46SIMA;                                RELEASE SIM.
        ACT,.205;                                    DEBRIEF SIM.
        FREE,PRIIPA;                                 RELEASE IP.
        ACT,.17,,CNT1;
```

```
*   SIMULATION CONTROL PROGRAM
*   BY CAPT. JOE NIEMEYER AND CAPT. MIKE SELVA
*   LAST REVISED:  11/16/84
      PROGRAM MAIN
      DIMENSION NSET(50000)
      COMMON/SCOM1/ ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      COMMON QSET(50000)
      EQUIVALENCE(NSET(1),QSET(1))
      NNSET=50000
      NCRDR=5
      NPRNT=6
      NTAPE=7
      OPEN(5,FILE='SLAMIN')
      OPEN(6,FILE='OUTPUT')
      CALL SLAM
      STOP
      END
*
*   INITIALIZATION ROUTINE
*
      SUBROUTINE INTLC
      COMMON/SCOM1/ ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      INTEGER I,J
      DIMENSION A(5)
*     INITIALIZE 16 (246/15=16.4) CLASSES INTO SUPT
*     INITIALIZE T-46 MODULES
      A(5)=.138
      DO 5 I=9,16
        A(1)=15*(I-1)
        A(2)=I
        A(3)=INT(68.*.125*(16-I))
        A(4)=INT(27.*.125*(16-I))
        DO 1 J=1,XX(4)-INT(XX(4)*.138*.125*(16-I))
 1        CALL ENTER(1,A)
        DO 2 J=1,XX(5)-INT(XX(5)*.138*.125*(16-I))
 2        CALL ENTER(2,A)
        DO 3 J=1,XX(6)-INT(XX(6)*.138*.125*(16-I))
 3        CALL ENTER(3,A)
        DO 4 J=1,XX(7)-INT(XX(7)*.138*.125*(16-I))
 4        CALL ENTER(4,A)
        DO 5 J=1,XX(8)-INT(XX(8)*.138*.125*(16-I))
 5        CALL ENTER(5,A)
```

```
PCSC   GOON;                              COLUMBUS PIPELINE.
       ACT/20,XX(2),,COLUM;

;
;  BASIC CLASS GENERATING ROUTINE
;
LAUGH  ASSIGN,XX(15)=XX(15)+1;                      COUNT INCOMING.
       AWAIT(1),GTLAU;                              WAIT FOR START.
       ASSIGN,XX(16)=XX(16)+1,1;                    COUNT STUDENTS.
       ACT,,XX(16).LT.XX(15).AND.XX(16).LT.XX(9),DR6;
       ACT;
       CLOSE,GTLAU;                                 CLOSEOUT CLASS.
       ASSIGN,XX(15)=XX(15)-XX(16),
              XX(16)=0;                             RESET COUNTERS.
       ACT,,,DR6;
WILLY  ASSIGN,XX(25)=XX(25)+1;
       AWAIT(2),GTWIL;
       ASSIGN,XX(26)=XX(26)+1,1;
       ACT,,XX(26).LT.XX(25).AND.XX(26).LT.XX(10),DR7;
       ACT;
       CLOSE,GTWIL;
       ASSIGN,XX(25)=XX(25)-XX(26),
              XX(26)=0;
       ACT,,,DR7;
REESE  ASSIGN,XX(35)=XX(35)+1;
       AWAIT(3),GTREE;
       ASSIGN,XX(36)=XX(36)+1,1;
       ACT,,XX(36).LT.XX(35).AND.XX(36).LT.XX(11),DR8;
       ACT;
       CLOSE,GTREE;
       ASSIGN,XX(35)=XX(35)-XX(36),
              XX(36)=0;
       ACT,,,DR8;
VANCE  ASSIGN,XX(45)=XX(45)+1;
       AWAIT(4),GTVAN;
       ASSIGN,XX(46)=XX(46)+1,1;
       ACT,,XX(46).LT.XX(45).AND.XX(46).LT.XX(12),DR9;
       ACT;
       CLOSE,GTVAN;
       ASSIGN,XX(45)=XX(45)-XX(46),
              XX(46)=0;
       ACT,,,DR9;
COLUM  ASSIGN,XX(55)=XX(55)+1;
       AWAIT(5),GTCOL;
       ASSIGN,XX(56)=XX(56)+1,1;
       ACT,,XX(56).LT.XX(55).AND.XX(56).LT.XX(13),DR0;
       ACT;
       CLOSE,GTCOL;
       ASSIGN,XX(55)=XX(55)-XX(56),
              XX(56)=0;
       ACT,,,DR0;
       ENDNETWORK;
FIN;
```

```
FAR3     ASSIGN,XX(71)=NNQ(2)+NNACT(17),
                XX(72)=NNQ(1)+NNACT(16),1;
         ACT,,XX(71).LT.XX(10),PCSW;
         ACT,,XX(72).LT.XX(9),PCSL;
         ACT,,XX(71).LE.XX(72),PCSW;
         ACT,,XX(71).GT.XX(72),PCSL;
TTB3     ASSIGN,XX(73)=NNQ(3)+NNACT(18),
                XX(74)=NNQ(4)+NNACT(19),
                XX(75)=NNQ(5)+NNACT(20),1;
         ACT,,XX(73).LT.XX(11),REESE;
         ACT,,XX(74).LT.XX(13),PCSC;
         ACT,,XX(75).LT.XX(12),PCSV;
         ACT,,XX(73).LE.XX(74).AND.XX(73).LE.XX(75),REESE;
         ACT,,XX(74).LE.XX(73).AND.XX(74).LE.XX(75),PCSC;
         ACT,,XX(75).LE.XX(73).AND.XX(75).LE.XX(74),PCSV;
FAR4     ASSIGN,XX(76)=NNQ(2)+NNACT(17),
                XX(77)=NNQ(1)+NNACT(16),1;
         ACT,,XX(76).LT.XX(10),PCSW;
         ACT,,XX(77).LT.XX(9),PCSL;
         ACT,,XX(76).LE.XX(77),PCSW;
         ACT,,XX(76).GT.XX(77),PCSL;
TTB4     ASSIGN,XX(78)=NNQ(4)+NNACT(19),
                XX(79)=NNQ(3)+NNACT(18),
                XX(80)=NNQ(5)+NNACT(20),1;
         ACT,,XX(78).LT.XX(12),VANCE;
         ACT,,XX(79).LT.XX(13),PCSC;
         ACT,,XX(80).LT.XX(11),PCSR;
         ACT,,XX(78).LE.XX(79).AND.XX(78).LE.XX(80),VANCE;
         ACT,,XX(79).LE.XX(78).AND.XX(79).LE.XX(80),PCSC;
         ACT,,XX(80).LE.XX(78).AND.XX(80).LE.XX(79),PCSR;
FAR5     ASSIGN,XX(81)=NNQ(1)+NNACT(16),
                XX(82)=NNQ(2)+NNACT(17),1;
         ACT,,XX(81).LT.XX(9),PCSL;
         ACT,,XX(82).LT.XX(10),PCSW;
         ACT,,XX(81).LE.XX(82),PCSL;
         ACT,,XX(81).GT.XX(82),PCSW;
TTB5     ASSIGN,XX(83)=NNQ(5)+NNACT(20),
                XX(84)=NNQ(4)+NNACT(19),
                XX(85)=NNQ(3)+NNACT(18),1;
         ACT,,XX(83).LT.XX(13),COLUM;
         ACT,,XX(84).LT.XX(12),PCSV;
         ACT,,XX(85).LT.XX(11),PCSR;
         ACT,,XX(83).LE.XX(84).AND.XX(83).LE.XX(85),COLUM;
         ACT,,XX(84).LE.XX(83).AND.XX(84).LE.XX(85),PCSV;
         ACT,,XX(85).LE.XX(83).AND.XX(85).LE.XX(84),PCSR;
PCSL     GOON;                          LAUGHLIN PIPELINE.
         ACT/16,XX(2),,LAUGH;
PCSW     GOON;                          WILLIAMS PIPELINE.
         ACT/17,XX(2),,WILLY;
PCSR     GOON;                          REESE PIPELINE.
         ACT/18,XX(2),,REESE;
PCSV     GOON;                          VANCE PIPELINE.
         ACT/19,XX(2),,VANCE;
```

```
SIMO    AWAIT(34),BASIPE;
        AWAIT(35),TTBSIMC;
        ACT,.125;
        ASSIGN,ATRIB(4)=ATRIB(4)+1;
        FREE,TTBSIMC;
        ACT,.205;
        FREE,BASIPE;
        ACT,.17,,CNTO;
COLO    COLCT,INT(1),COLUM TOTAL DAYS;
        ASSIGN,XX(58)=231+15*ATRIB(2)-TNOW,1;
        ACT,XX(58),XX(58).GE.O,GRDO;
        ACT;
        COLCT,XX(58),COLUM TOTAL LATE;
GRDO    COLCT,INT(1),COLUM GRADUATES;
        TERM;

;
;   ASSIGNMENT MODULE
;
FAR1    ASSIGN,XX(61)=NNQ(1)+NNACT(16),
               XX(62)=NNQ(2)+NNACT(17),1;
        ACT,,XX(61).LT.XX(9),LAUGH;
        ACT,,XX(62).LT.XX(10),PCSW;
        ACT,,XX(61).LE.XX(62),LAUGH;
        ACT,,XX(61).GT.XX(62),PCSW;
TTB1    ASSIGN,XX(63)=NNQ(3)+NNACT(18),
               XX(64)=NNQ(4)+NNACT(19),
               XX(65)=NNQ(5)+NNACT(20),1;
        ACT,,XX(63).LT.XX(11),PCSR;
        ACT,,XX(64).LT.XX(13),PCSC;
        ACT,,XX(65).LT.XX(12),PCSV;
        ACT,,XX(63).LE.XX(64).AND.XX(63).LE.XX(65),PCSR;
        ACT,,XX(64).LE.XX(63).AND.XX(64).LE.XX(65),PCSC;
        ACT,,XX(65).LE.XX(63).AND.XX(65).LE.XX(64),PCSV;
FAR2    ASSIGN,XX(66)=NNQ(2)+NNACT(17),
               XX(67)=NNQ(1)+NNACT(16),1;
        ACT,,XX(66).LT.XX(10),WILLY;
        ACT,,XX(67).LT.XX(9),PCSL;
        ACT,,XX(66).LE.XX(67),WILLY;
        ACT,,XX(66).GT.XX(67),PCSL;
TTB2    ASSIGN,XX(68)=NNQ(3)+NNACT(18),
               XX(69)=NNQ(4)+NNACT(19),
               XX(70)=NNQ(5)+NNACT(20),1;
        ACT,,XX(68).LT.XX(12),PCSV;
        ACT,,XX(69).LT.XX(11),PCSR;
        ACT,,XX(70).LT.XX(13),PCSC;
        ACT,,XX(68).LE.XX(69).AND.XX(68).LE.XX(70),PCSV;
        ACT,,XX(69).LE.XX(68).AND.XX(69).LE.XX(70),PCSR;
        ACT,,XX(70).LE.XX(68).AND.XX(70).LE.XX(69),PCSC;
```

```
COL5     COLCT,INT(1),COLUM DAYS PRIM;
         ASSIGN,ATRIB(3)=0,
                 ATRIB(4)=0,
                 XX(52)=108+15*ATRIB(2)-TNOW,1;
         ACT,XX(52),XX(52).GE.0,GRD5;
         ACT;
         COLCT,XX(52),COLM PRIM LATE;
GRD5     GOON,1;
         ACT,,XX(1),FAR5;
         ACT,,1-XX(1),TTB5;
;
;   COLUMBUS TTB MODULE
;
ORO      ASSIGN,ATRIB(5)=USERF(5);
         ACT,,,CNTO;
         ENTER,10;
CNTO     GOON,1;
         ACT,,ATRIB(3).LT.61.AND.NNRSC(TTBC).GE.1.AND.NNRSC(BASIPE).GE.1,FLYO;
         ACT,,ATRIB(4).LT.27.AND.NNRSC(TTBSIMC).GE.1.AND.NNRSC(BASIPE).GE.1,SIMO;
         ACT,,ATRIB(3).GE.61.AND.ATRIB(4).GE.27,COLO;
         ACT,.33,,CNTO;
FLYO     ASSIGN,XX(59)=USERF(20),1;
         ACT,,XX(59),WXO;
         ACT,,1-XX(59);
         AWAIT(34),BASIPE;
PLNO     AWAIT(33),TTBC;
         ASSIGN,XX(60)=USERF(9),1;
         ACT,,XX(60),BRKO;
         ACT,.36,1-XX(60);
         ASSIGN,ATRIB(3)=ATRIB(3)+1;
         FREE,TTBC;
         ACT,.14;
         FREE,BASIPE;
         ASSIGN,XX(57)=USERF(6),1;
         ACT,.5,1-XX(57),CNTO;
         ACT/15,,XX(57);
         TERM;
WXO      GOON,1;
         ACT,,ATRIB(4).LT.27.AND.NNRSC(TTBSIMC).GE.1,SIMO;
         ACT,.33,,CNTO;
BRKO     GOON,2;
         ACT,,,FIXO;
         ACT,,NNRSC(TTBC).GE.1,PLNO;
         ACT;
         FREE,BASIPE;
         ACT,.33,,CNTO;
FIXO     GOON;
         ACT,.12;
         FREE,TTBC;
         TERM;
```

```
GRD9    COLCT,INT(1),VANCE GRADUATES;
        TERM;

;
;   COLUMBUS T-46 MODULE
;
DR5     ASSIGN,ATRIB(5)=USERF(1);
        ACT,37,,CNT5;
        ENTER,5;
CNT5    GOON,1;
        ACT,,ATRIB(3).LT.68.AND.NNRSC(T46E).GE.1.AND.NNRSC(PRIIPE).GE.1,FLY5;
        ACT,,ATRIB(4).LT.27.AND.NNRSC(T46SIME).GE.1.AND.NNRSC(PRIIPE).GE.1,SIM5;
        ACT,,ATRIB(3).GE.68.AND.ATRIB(4).GE.27,COL5;
        ACT,.33,,CNT5;
FLY5    ASSIGN,XX(53)=USERF(19),1;
        ACT,,XX(53),WX5;
        ACT,,1-XX(53);
        AWAIT(31),PRIIPE;
PLN5    AWAIT(30),T46E;
        ASSIGN,XX(54)=USERF(7),1;
        ACT,,XX(54),BRK5;
        ACT,.22,1-XX(54);
        ASSIGN,ATRIB(3)=ATRIB(3)+1;
        FREE,T46E;
        ACT,.11;
        FREE,PRIIPE;
        ASSIGN,XX(51)=USERF(2),1;
        ACT,.17,1-XX(51),CNT5;
        ACT/14,,XX(51);
        TERM;
WX5     GOON,1;
        ACT,,ATRIB(4).LT.27.AND.NNRSC(T46SIME).GE.1,SIM5;
        ACT,.33,,CNT5;
BRK5    GOON,2;
        ACT,,,FIX5;
        ACT,,NNRSC(T46E).GE.1,PLN5;
        ACT;
        FREE,PRIIPE;
        ACT,.33,,CNT5;
FIX5    GOON;
        ACT,.12;
        FREE,T46E;
        TERM;
SIM5    AWAIT(31),PRIIPE;
        AWAIT(32),T46SIME;
        ACT,.125;
        ASSIGN,ATRIB(4)=ATRIB(4)+1;
        FREE,T46SIME;
        ACT,.205;
        FREE,PRIIPE;
        ACT,.17,,CNT5;
```

```
;
;   VANCE TTB MODULE
;
DR9      ASSIGN,ATRIB(5)=USERF(5);
         ACT,,,CNT9;
         ENTER,9;
CNT9     GOON,1;
         ACT,,ATRIB(3).LT.61.AND.NNRSC(TTBB).GE.1.AND.NNRSC(BASIPD).GE.1,FLY9;
         ACT,,ATRIB(4).LT.27.AND.NNRSC(TTBSIMB).GE.1.AND.NNRSC(BASIPD).GE.1,SIM9;
         ACT,,ATRIB(3).GE.61.AND.ATRIB(4).GE.27,COL9;
         ACT,.33,,CNT9;
FLY9     ASSIGN,XX(49)=USERF(18),1;
         ACT,,XX(49),WX9;
         ACT,,1-XX(49);
         AWAIT(28),BASIPD;
PLN9     AWAIT(27),TTBB;
         ASSIGN,XX(50)=USERF(9),1;
         ACT,,XX(50),BRK9;
         ACT,.36,1-XX(50);
         ASSIGN,ATRIB(3)=ATRIB(3)+1;
         FREE,TTBB;
         ACT,.14;
         FREE,BASIPD;
         ASSIGN,XX(47)=USERF(6),1;
         ACT,.5,1-XX(47),CNT9;
         ACT/13,,XX(47);
         TERM;
WX9      GOON,1;
         ACT,,ATRIB(4).LT.27.AND.NNRSC(TTBSIMB).GE.1,SIM9;
         ACT,.33,,CNT9;
BRK9     GOON,2;
         ACT,,,FIX9;
         ACT,,NNRSC(TTBB).GE.1,PLN9;
         ACT;
         FREE,BASIPD;
         ACT,.33,,CNT9;
FIX9     GOON;
         ACT,.12;
         FREE,TTBB;
         TERM;
SIM9     AWAIT(28),BASIPD;
         AWAIT(29),TTBSIMB;
         ACT,.125;
         ASSIGN,ATRIB(4)=ATRIB(4)+1;
         FREE,TTBSIMB;
         ACT,.205;
         FREE,BASIPD;
         ACT,.17,,CNT9;
COL9     COLCT,INT(1),VANCE TOTAL DAYS;
         ASSIGN,XX(48)=231+15*ATRIB(2)-TNOW,1;
         ACT,XX(48),XX(48).GE.0,GRD9;
         ACT;
         COLCT,XX(48),VANCE TOTAL LATE;
```

```
FLY4    ASSIGN,XX(43)=USERF(17),1;
        ACT,,XX(43),WX4;
        ACT,,1-XX(43);
        AWAIT(25),PRIIPD;
PLN4    AWAIT(24),T46D;
        ASSIGN,XX(44)=USERF(7),1;
        ACT,,XX(44),BRK4;
        ACT,.22,1-XX(44);
        ASSIGN,ATRIB(3)=ATRIB(3)+1;
        FREE,T46D;
        ACT,.11;
        FREE,PRIIPD;
        ASSIGN,XX(41)=USERF(2),1;
        ACT,.17,1-XX(41),CNT4;
        ACT/12,,XX(41);
        TERM;
WX4     GOON,1;
        ACT,,ATRIB(4).LT.27.AND.NNRSC(T46SIMD).GE.1,SIM4;
        ACT,.33,,CNT4;
BRK4    GOON,2;
        ACT,,,FIX4;
        ACT,,NNRSC(T46D).GE.1,PLN4;
        ACT;
        FREE,PRIIPD;
        ACT,.33,,CNT4;
FIX4    GOON;
        ACT,.12;
        FREE,T46D;
        TERM;
SIM4    AWAIT(25),PRIIPD;
        AWAIT(26),T46SIMD;
        ACT,.125;
        ASSIGN,ATRIB(4)=ATRIB(4)+1;
        FREE,T46SIMD;
        ACT,.205;
        FREE,PRIIPD;
        ACT,.17,,CNT4;
COL4    COLCT,INT(1),VANCE DAYS PRIM;
        ASSIGN,ATRIB(3)=0,
               ATRIB(4)=0,
               XX(42)=108+15*ATRIB(2)-TNOW,1;
        ACT,XX(42),XX(42).GE.0,GRD4;
        ACT;
        COLCT,XX(42),VANCE PRIM LATE;
GRD4    GOON,1;
        ACT,,XX(1),FAR4;
        ACT,,1-XX(1),TTB4;
```

```
PLN8    AWAIT(21),TTBA;
        ASSIGN,XX(40)=USERF(9),1;
        ACT,,XX(40),BRK8;
        ACT,.36,1-XX(40);
        ASSIGN,ATRIB(3)=ATRIB(3)+1;
        FREE,TTBA;
        ACT,.14;
        FREE,BASIPC;
        ASSIGN,XX(37)=USERF(6),1;
        ACT,.5,1-XX(37),CNT8;
        ACT/11,,XX(37);
        TERM;
WX8     GOON,1;
        ACT,,ATRIB(4).LT.27.AND.NNRSC(TTBSIMA).GE.1,SIM8;
        ACT,.33,,CNT8;
BRK8    GOON,2;
        ACT,,,FIX8;
        ACT,,NNRSC(TTBA).GE.1,PLN8;
        ACT;
        FREE,BASIPC;
        ACT,.33,,CNT8;
FIX8    GOON;
        ACT,.12;
        FREE,TTBA;
        TERM;
SIM8    AWAIT(22),BASIPC;
        AWAIT(23),TTBSIMA;
        ACT,.125;
        ASSIGN,ATRIB(4)=ATRIB(4)+1;
        FREE,TTBSIMA;
        ACT,.205;
        FREE,BASIPC;
        ACT,.17,,CNT8;
COL8    COLCT,INT(1),REESE TOTAL DAYS;
        ASSIGN,XX(38)=231+15*ATRIB(2)-TNOW,1;
        ACT,XX(38),XX(38).GE.0,GRD8;
        ACT;
        COLCT,XX(38),REESE TOTAL LATE;
GRD8    COLCT,INT(1),REESE GRADUATES;
        TERM;
;
;   VANCE T-46 MODULE
;
DR4     ASSIGN,ATRIB(5)=USERF(1);
        ACT,37,,CNT4;
        ENTER,4;
CNT4    GOON,1;
        ACT,,ATRIB(3).LT.68.AND.NNRSC(T46D).GE.1.AND.NNRSC(PRIIPD).GE.1,FLY4;
        ACT,,ATRIB(4).LT.27.AND.NNRSC(T46SIMD).GE.1.AND.NNRSC(PRIIPD).GE.1,SIM4;
        ACT,,ATRIB(3).GE.68.AND.ATRIB(4).GE.27,COL4;
        ACT,.33,,CNT4;
```

```
WX3      GOON,1;
         ACT,,ATRIB(4).LT.27.AND.NNRSC(T46SIMC).GE.1,SIM3;
         ACT,.33,,CNT3;
BRK3     GOON,2;
         ACT,,,FIX3;
         ACT,,NNRSC(T46C).GE.1,PLN3;
         ACT;
         FREE,PRIIPC;
         ACT,.33,,CNT3;
FIX3     GOON;
         ACT,.12;
         FREE,T46C;
         TERM;
SIM3     AWAIT(19),PRIIPC;
         AWAIT(20),T46SIMC;
         ACT,.125;
         ASSIGN,ATRIB(4)=ATRIB(4)+1;
         FREE,T46SIMC;
         ACT,.205;
         FREE,PRIIPC;
         ACT,.17,,CNT3;
COL3     COLCT,INT(1),REESE DAYS PRIM;
         ASSIGN,ATRIB(3)=0,
                ATRIB(4)=0,
                XX(32)=108+15*ATRIB(2)-TNOW,1;
         ACT,XX(32),XX(32).GE.0,GRD3;
         ACT;
         COLCT,XX(32),REESE PRIM LATE;
GRD3     GOON,1;
         ACT,,XX(1),FAR3;
         ACT,,1-XX(1),TTB3;
;
;   REESE TTB MODULE
;
DR8      ASSIGN,ATRIB(5)=USERF(5);
         ACT,,,CNT8;
         ENTER,8;
CNT8     GOON,1;
         ACT,,ATRIB(3).LT.61.AND.NNRSC(TTBA).GE.1.AND.NNRSC(BASIPC).GE.1,FLY8;
         ACT,,ATRIB(4).LT.27.AND.NNRSC(TTBSIMA).GE.1.AND.NNRSC(BASIPC).GE.1,SIM8;
         ACT,,ATRIB(3).GE.61.AND.ATRIB(4).GE.27,COL8;
         ACT,.33,,CNT8;
FLY8     ASSIGN,XX(39)=USERF(16),1;
         ACT,,XX(39),WX8;
         ACT,,1-XX(39);
         AWAIT(22),BASIPC;
```

```
BRK7    GOON,2;
        ACT,,,FIX7;
        ACT,,NNRSC(T38B).GE.1,PLN7;
        ACT;
        FREE,BASIPB;
        ACT,.33,,CNT7;
FIX7    GOON;
        ACT,.12;
        FREE,T38B;
        TERM;
SIM7    AWAIT(16),BASIPB;
        AWAIT(17),T38SIMB;
        ACT,.125;
        ASSIGN,ATRIB(4)=ATRIB(4)+1;
        FREE,T38SIMB;
        ACT,.205;
        FREE,BASIPB;
        ACT,.17,,CNT7;
COL7    COLCT,INT(1),WILLY TOTAL DAYS;
        ASSIGN,XX(28)=231+15*ATRIB(2)-TNOW,1;
        ACT,XX(28),XX(28).GE.0,GRD7;
        ACT;
        COLCT,XX(28),WILLY TOTAL LATE;
GRD7    COLCT,INT(1),WILLY GRADUATES;
        TERM;
;
;  REESE T-46 MODULE
;
DR3     ASSIGN,ATRIB(5)=USERF(1);
        ACT,37,,CNT3;
        ENTER,3;
CNT3    GOON,1;
        ACT,,ATRIB(3).LT.68.AND.NNRSC(T46C).GE.1.AND.NNRSC(PRIIPC).GE.1,FLY3;
        ACT,,ATRIB(4).LT.27.AND.NNRSC(T46SIMC).GE.1.AND.NNRSC(PRIIPC).GE.1,SIM3;
        ACT,,ATRIB(3).GE.68.AND.ATRIB(4).GE.27,COL3;
        ACT,.33,,CNT3;
FLY3    ASSIGN,XX(33)=USERF(15),1;
        ACT,,XX(33),WX3;
        ACT,,1-XX(33);
        AWAIT(19),PRIIPC;
PLN3    AWAIT(18),T46C;
        ASSIGN,XX(34)=USERF(7),1;
        ACT,,XX(34),BRK3;
        ACT,.22,1-XX(34);
        ASSIGN,ATRIB(3)=ATRIB(3)+1;
        FREE,T46C;
        ACT,.11;
        FREE,PRIIPC;
        ASSIGN,XX(31)=USERF(2),1;
        ACT,.17,1-XX(31),CNT3;
        ACT/10,,XX(31);
        TERM;
```

```
FIX2    GOON;
        ACT,.12;
        FREE,T46B;
        TERM;
SIM2    AWAIT(13),PRIIPB;
        AWAIT(14),T46SIMB;
        ACT,.125;
        ASSIGN,ATRIB(4)=ATRIB(4)+1;
        FREE,T46SIMB;
        ACT,.205;
        FREE,PRIIPB;
        ACT,.17,,CNT2;
COL2    COLCT,INT(1),WILLY DAYS PRIM;
        ASSIGN,ATRIB(3)=0,
               ATRIB(4)=0,
               XX(22)=108+15*ATRIB(2)-TNOW,1;
        ACT,XX(22),XX(22).GE.0,GRD2;
        ACT;
        COLCT,XX(22),WILLY PRIM LATE;
GRD2    GOON,1;
        ACT,,XX(1),FAR2;
        ACT,,1-XX(1),TTB2;
;
;   WILLIAMS'S T-38 MODULE
;
DR7     ASSIGN,ATRIB(5)=USERF(3);
        ACT,,,CNT7;
        ENTER,7;
CNT7    GOON,1;
        ACT,,ATRIB(3).LT.89.AND.NNRSC(T38B).GE.1.AND.NNRSC(BASIPB).GE.1,FLY7;
        ACT,,ATRIB(4).LT.27.AND.NNRSC(T38SIMB).GE.1.AND.NNRSC(BASIPB).GE.1,SIM7;
        ACT,,ATRIB(3).GE.89.AND.ATRIB(4).GE.27,COL7;
        ACT,.33,,CNT7;
FLY7    ASSIGN,XX(29)=USERF(14),1;
        ACT,,XX(29),WX7;
        ACT,,1-XX(29);
        AWAIT(16),BASIPB;
PLN7    AWAIT(15),T38B;
        ASSIGN,XX(30)=USERF(8),1;
        ACT,,XX(30),BRK7;
        ACT,.22,1-XX(30);
        ASSIGN,ATRIB(3)=ATRIB(3)+1;
        FREE,T38B;
        ACT,.11;
        FREE,BASIPB;
        ASSIGN,XX(27)=USERF(4),1;
        ACT,.17,1-XX(27),CNT7;
        ACT/9,,XX(27);
        TERM;
WX7     GOON,1;
        ACT,,ATRIB(4).LT.27.AND.NNRSC(T38SIMB).GE.1,SIM7;
        ACT,.33,,CNT7;
```

C-6

```
SIM6    AWAIT(10),BASIPA;
        AWAIT(11),T38SIMA;
        ACT,.125;
        ASSIGN,ATRIB(4)=ATRIB(4)+1;
        FREE,T38SIMA;
        ACT,.205;
        FREE,BASIPA;
        ACT,.17,,CNT6;
COL6    COLCT,INT(1),LAUGH TOTAL DAYS;
        ASSIGN,XX(18)=231+15*ATRIB(2)-TNOW,1;
        ACT,XX(18),XX(18).GE.0,GRD6;
        ACT;
        COLCT,XX(18),LAUGH TOTAL LATE;
GRD6    COLCT,INT(1),LAUGH GRADUATES;
        TERM;
;
;   WILLIAM'S T-46 MODULE
;
OR2     ASSIGN,ATRIB(5)=USERF(1);
        ACT,37,,CNT2;
        ENTER,2;
CNT2    GOON,1;
        ACT,,ATRIB(3).LT.68.AND.NNRSC(T46B).GE.1.AND.NNRSC(PRIIPB).GE.1,FLY2;
        ACT,,ATRIB(4).LT.27.AND.NNRSC(T46SIMB).GE.1.AND.NNRSC(PRIIPB).GE.1,SIM2;
        ACT,,ATRIB(3).GE.68.AND.ATRIB(4).GE.27,COL2;
        ACT,.33,,CNT2;
FLY2    ASSIGN,XX(23)=USERF(13),1;
        ACT,,XX(23),WX2;
        ACT,,1-XX(23);
        AWAIT(13),PRIIPB;
PLN2    AWAIT(12),T46B;
        ASSIGN,XX(24)=USERF(7),1;
        ACT,,XX(24),BRK2;
        ACT,.22,1-XX(24);
        ASSIGN,ATRIB(3)=ATRIB(3)+1;
        FREE,T46B;
        ACT,.11;
        FREE,PRIIPB;
        ASSIGN,XX(21)=USERF(2),1;
        ACT,.17,1-XX(21),CNT2;
        ACT/8,,XX(21);
        TERM;
WX2     GOON,1;
        ACT,,ATRIB(4).LT.27.AND.NNRSC(T46SIMB).GE.1,SIM2;
        ACT,.33,,CNT2;
BRK2    GOON,2;
        ACT,,,FIX2;
        ACT,,NNRSC(T46B).GE.1,PLN2;
        ACT;
        FREE,PRIIPB;
        ACT,.33,,CNT2;
```

```
COL1    COLCT,INT(1),LAUGH DAYS PRIM;              FINISHED WITH PRIMARY!
        ASSIGN,ATRIB(3)=0,
               ATRIB(4)=0;                         RESET SORTIE/SIM COUNT.
        ASSIGN,XX(88)=108+15*ATRIB(2)-TNOW,1;      COMPUTE DAYS EARLY.
        ACT,XX(88),XX(88).GE.0,GRD1;               FINISHED EARLY?
        ACT;                                       FINISHED LATE?
        COLCT,XX(88),LAUGH PRIM LATE;
GRD1    GOON,1;
        ACT,,XX(1),FAR1;                           ADVANCED TRAINING
        ACT,,1-XX(1),TTB1;                         RECOMMENDATION BOARD




;
;   LAUGHLIN T-38 MODULE
;
DR6     ASSIGN,ATRIB(5)=USERF(3);
        ACT,,,CNT6;
        ENTER,6;
CNT6    GOON,1;
        ACT,,ATRIB(3).LT.89.AND.NNRSC(T38A).GE.1.AND.NNRSC(BASIPA).GE.1,FLY6;
        ACT,,ATRIB(4).LT.27.AND.NNRSC(T38SIMA).GE.1.AND.NNRSC(BASIPA).GE.1,SIM6;
        ACT,,ATRIB(3).GE.89.AND.ATRIB(4).GE.27,COL6;
        ACT,.33,,CNT6;
FLY6    ASSIGN,XX(19)=USERF(12),1;
        ACT,,XX(19),WX6;
        ACT,,1-XX(19);
        AWAIT(10),BASIPA;
PLN6    AWAIT(9),T38A;
        ASSIGN,XX(20)=USERF(8),1;
        ACT,,XX(20),BRK6;
        ACT,.22,1-XX(20);
        ASSIGN,ATRIB(3)=ATRIB(3)+1;
        FREE,T38A;
        ACT,.11;
        FREE,BASIPA;
        ASSIGN,XX(17)=USERF(4),1;
        ACT,.17,1-XX(17),CNT6;
        ACT/7,,XX(17);
        TERM;
WX6     GOON,1;
        ACT,,ATRIB(4).LT.27.AND.NNRSC(T38SIMA).GE.1,SIM6;
        ACT,.33,,CNT6;
BRK6    GOON,2;
        ACT,,,FIX6;
        ACT,,NNRSC(T38A).GE.1,PLN6;
        ACT;
        FREE,BASIPA;
        ACT,.33,,CNT6;
FIX6    GOON;
        ACT,.12;
        FREE,T38A;
        TERM;
```

```
*       INITIALIZE T-38 MODULES
        A(5)=.053
        DO 10 I=1,8
          A(1)=15*(I-1)
          A(2)=I
          A(3)=INT(89.*.125*(8-I))
          A(4)=INT(27.*.125*(8-I))
          DO 6 J=1,XX(9)-INT(XX(9)*.053*.125*(8-I))
    6       CALL ENTER(6,A)
          DO 7 J=1,XX(10)-INT(XX(10)*.053*.125*(8-I))
    7       CALL ENTER(7,A)
*           INITIALIZE TTB MODULES
          A(3)=INT(61.*.125*(8-I))
          DO 8 J=1,XX(11)-INT(XX(11)*.053*.125*(8-I))
    8       CALL ENTER(8,A)
          DO 9 J=1,XX(12)-INT(XX(12)*.053*.125*(8-I))
    9       CALL ENTER(9,A)
          DO 10 J=1,XX(13)-INT(XX(13)*.053*.125*(8-I))
   10       CALL ENTER(10,A)
      RETURN
      END
*
*  PROBABILITY DISTRIBUTIONS. AND CALENDAR FUNCTION
*
      FUNCTION USERF(I)
      COMMON/SCOM1/ ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      REAL USERF,X
      INTEGER I,Y
*
*  ALL WEATHER DRAWS FIRST GO TO 10 TO DETERMINE SEASON OF THE YEAR
*
      GO TO (1,2,3,4,5,6,7,8,9,10,10,10,10,10,10,10,10,10,10,10),I
*
*  T-46 ATTRITION RATE
*
    1 USERF=RNORM(.138,.039,1)
      IF (USERF.LE.0.) THEN
        GO TO 1
      ENDIF
      RETURN
```

```
*
*  T-46 ATTRITION ROUTINE
*

    2 IF (ATRIB(3).EQ.17.) THEN
        USERF=ATRIB(5)*.21
      ELSEIF (ATRIB(3).EQ.34.) THEN
        USERF=ATRIB(5)*.41
      ELSEIF (ATRIB(3).EQ.51.) THEN
        USERF=ATRIB(5)*.25
      ELSEIF (ATRIB(3).EQ.68.) THEN
        USERF=ATRIB(5)*.13
      ELSE
        USERF=0.
      ENDIF
      RETURN
*
*  T-38 ATTRITION RATE
*

    3 USERF=RNORM(.053,.019,2)
      IF (USERF.LE.0.) THEN
        GO TO 3
      ENDIF
      RETURN
*
*  T-38 ATTRITION ROUTINE
*

    4 IF (ATRIB(3).EQ.22.) THEN
        USERF=ATRIB(5)*.12
      ELSEIF (ATRIB(3).EQ.45.) THEN
        USERF=ATRIB(5)*.53
      ELSEIF (ATRIB(3).EQ.67.) THEN
        USERF=ATRIB(5)*.29
      ELSEIF (ATRIB(3).EQ.89.) THEN
        USERF=ATRIB(5)*.06
      ELSE
        USERF=0.
      ENDIF
      RETURN
*
*  TTB ATTRITION RATE
*

    5 USERF=RNORM(.053,.019,3)
      IF (USERF.LE.0.) THEN
        GO TO 5
      ENDIF
      RETURN
```

```
*
*  TTB ATTRITION ROUTINE
*
    6 IF (ATRIB(3).EQ.8.) THEN
        USERF=ATRIB(5)*.12
      ELSEIF (ATRIB(3).EQ.16.) THEN
        USERF=ATRIB(5)*.53
      ELSEIF (ATRIB(3).EQ.23.) THEN
        USERF=ATRIB(5)*.29
      ELSEIF (ATRIB(3).EQ.31.) THEN
        USERF=ATRIB(5)*.06
      ELSE
        USERF=0.
      ENDIF
      RETURN
*
*  T-46 GROUND MAINTENANCE ABORT RATE
*
    7 USERF=RNORM(.026,.005,4)
      IF (USERF.LE.O.) THEN
        GO TO 7
      ENDIF
      RETURN
*
*  T-38 GROUND MAINTENANCE ABORT RATE
*
    8 USERF=RNORM(.031,.003,5)
      IF (USERF.LE.O.) THEN
        GO TO 8
      ENDIF
      RETURN
*
*  TTB GROUND MAINTENANCE ABORT RATE
*
    9 USERF=RNORM(.031,.003,6)
      IF (USERF.LE.O.) THEN
        GO TO 9
      ENDIF
      RETURN
```

```
*
*   COMPUTE CALENDAR DAY AND SEASON
*   USING 246 WORKING DAYS IN A YEAR
*   WINTER=1, SPRING=2, SUMMER=3, FALL=4
*
    10 X=TNOW-INT(TNOW/246.)*246.
       IF (X.GE.0..AND.X.LE.62.) THEN
          Y=1
       ELSEIF (X.GT.62..AND.X.LE.126.) THEN
          Y=2
       ELSEIF (X.GT.126..AND.X.LE.190.) THEN
          Y=3
       ELSE
          Y=4
       ENDIF
       GO TO (1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20),I
*
*   LAUGHLIN T-46 WEATHER ABORT RATE
*
    11 IF (Y.EQ.1) THEN
          USERF=RNORM(.266,.090,7)
       ELSEIF (Y.EQ.2) THEN
          USERF=RNORM(.226,.130,8)
       ELSEIF (Y.EQ.3) THEN
          USERF=RNORM(.134,.063,9)
       ELSE
          USERF=RNORM(.182,.070,10)
       ENDIF
       IF (USERF.LE.0.) THEN
          GO TO 11
       ENDIF
       RETURN
*
*   LAUGHLIN T-38 WEATHER ABORT RATE
*
    12 IF (Y.EQ.1) THEN
          USERF=RNORM(.268,.088,7)
       ELSEIF (Y.EQ.2) THEN
          USERF=RNORM(.245,.100,8)
       ELSEIF (Y.EQ.3) THEN
          USERF=RNORM(.156,.054,9)
       ELSE
          USERF=RNORM(.204,.078,10)
       ENDIF
       IF (USERF.LE.0.) THEN
          GO TO 12
       ENDIF
       RETURN
```

```
*
*   WILLIAMS T-46 WEATHER ABORT RATE
*
    13 IF (Y.EQ.1) THEN
          USERF=RNORM(.127,.073,7)
       ELSEIF (Y.EQ.2) THEN
         USERF=RNORM(.068,.051,8)
       ELSEIF (Y.EQ.3) THEN
         USERF=RNORM(.069,.038,9)
       ELSE
         USERF=RNORM(.050,.058,10)
       ENDIF
       IF (USERF.LE.0.) THEN
         GO TO 13
       ENDIF
       RETURN
*
*   WILLIAMS T-38 WEATHER ABORT RATE
*
    14 IF (Y.EQ.1) THEN
          USERF=RNORM(.143,.087,7)
       ELSEIF (Y.EQ.2) THEN
         USERF=RNORM(.055,.030,8)
       ELSEIF (Y.EQ.3) THEN
         USERF=RNORM(.094,.039,9)
       ELSE
         USERF=RNORM(.063,.058,10)
       ENDIF
       IF (USERF.LE.0.) THEN
         GO TO 14
       ENDIF
       RETURN
*
*   REESE T-46 WEATHER ABORT RATE
*
    15 IF (Y.EQ.1) THEN
          USERF=RNORM(.337,.083,7)
       ELSEIF (Y.EQ.2) THEN
         USERF=RNORM(.274,.100,8)
       ELSEIF (Y.EQ.3) THEN
         USERF=RNORM(.137,.077,9)
       ELSE
         USERF=RNORM(.267,.122,10)
       ENDIF
       IF (USERF.LE.0.) THEN
         GO TO 15
       ENDIF
       RETURN
```

```
*
*   REESE TTB WEATHER ABORT RATE
*
    16 IF (Y.EQ.1) THEN
          USERF=RNORM(.318,.091,7)
       ELSEIF (Y.EQ.2) THEN
          USERF=RNORM(.275,.101,8)
       ELSEIF (Y.EQ.3) THEN
          USERF=RNORM(.166,.077,9)
       ELSE
          USERF=RNORM(.247,.108,10)
       ENDIF
       IF (USERF.LE.0.) THEN
          GO TO 16
       ENDIF
       RETURN
*
*   VANCE T-46 WEATHER ABORT RATE
*
    17 IF (Y.EQ.1) THEN
          USERF=RNORM(.299,.119,7)
       ELSEIF (Y.EQ.2) THEN
          USERF=RNORM(.222,.069,8)
       ELSEIF (Y.EQ.3) THEN
          USERF=RNORM(.099,.051,9)
       ELSE
          USERF=RNORM(.204,.077,10)
       ENDIF
       IF (USERF.LE.0.) THEN
          GO TO 17
       ENDIF
       RETURN
*
*   VANCE TTB WEATHER ABORT RATE
*
    18 IF (Y.EQ.1) THEN
          USERF=RNORM(.319,.143,7)
       ELSEIF (Y.EQ.2) THEN
          USERF=RNORM(.245,.074,8)
       ELSEIF (Y.EQ.3) THEN
          USERF=RNORM(.122,.069,9)
       ELSE
          USERF=RNORM(.217,.090,10)
       ENDIF
       IF (USERF.LE.0.) THEN
          GO TO 18
       ENDIF
       RETURN
```

```
*
*   COLUMBUS T-46 WEATHER ABORT RATE
*

   19 IF (Y.EQ.1) THEN
         USERF=RNORM(.304,.087,7)
      ELSEIF (Y.EQ.2) THEN
        USERF=RNORM(.240,.064,8)
      ELSEIF (Y.EQ.3) THEN
        USERF=RNORM(.233,.100,9)
      ELSE
        USERF=RNORM(.222,.065,10)
      ENDIF
      IF (USERF.LE.O.) THEN
        GO TO 19
      ENDIF
      RETURN
*
*   COLUMBUS TTB WEATHER ABORT RATE
*

   20 IF (Y.EQ.1) THEN
         USERF=RNORM(.300,.117,7)
      ELSEIF (Y.EQ.2) THEN
        USERF=RNORM(.223,.068,8)
      ELSEIF (Y.EQ.3) THEN
        USERF=RNORM(.222,.083,9)
      ELSE
        USERF=RNORM(.218,.053,10)
      ENDIF
      IF (USERF.LE.O.) THEN
        GO TO 20
      ENDIF
      RETURN
      END
```

Appendix E: Statistical Analysis Package

```
10  '                    Statistical Analysis Package
20  '                   in Microsoft BASIC version 2.10
30  '                        by Joseph B. Niemeyer
40  '
50  '     This statistical analysis package provides some common
60  '     statistical tests used in experimental design.  Most
70  '     of the modules require that you provide a data file
80  '     according to the format shown below.  The data files
90  '     can be created with any text editor.
100 '
110 '              Format of data file for One-way ANOVA:
120 '                    #Runs,#Replications
130 '                    "Report Title"
140 '                    "Run 1 Label","Run 2 Label", . . .
150 '                    Y(1,1),Y(1,2), . . .
160 '                    Y(2,1),Y(2,2), . . .
170 '                    . . .
180 '
190 '              Format of data file for Two-way ANOVA:
200 '                    #A Levels,#B Levels,#Replications
210 '                    "Report Title"
220 '                    "Factor A Name","Factor B Name"
230 '                    Y(A1,B1,1),Y(A1,B1,2), . . .
240 '                    Y(A1,B2,1),Y(A1,B2,2), . . .
250 '                    . . .
260 '                    Y(A2,B1,1),Y(A2,B1,2), . . .
270 '                    Y(A2,B2,1),Y(A2,B2,2), . . .
280 '                    . . .
290 '
300 '              Format of data file for Multiple Regression:
310 '                    #Independent Variables,#Observations
320 '                    "Report Title"
330 '                    "Var 1 Name","Var 2 Name", . . .
340 '                    Y(1) X(1,1) X(2,1) . . .
350 '                    Y(2) X(1,2) X(2,2) . . .
360 '                    . . .
370 '
380 '              Format of data file for Factorial Analysis:
390 '                    #Dependent Variables,#Effects,#Runs,#Reps
400 '                    "Report Title 1","Report Title 2", . . .
410 '                    "Effect 1","Effect 2", . . .
420 '                    1 -1 -1 -1  1  1  1 -1 . . .
430 '                    1 -1 -1 -1  1  1  1 -1 . . .
440 '                    . . .
450 '                    Y(1,1) Y(2,1) . . .
460 '                    Y(1,2) Y(2,2) . . .
470 '                    . . .
480 '
```

```
490 '                 Format of data file for Kolmogorov-Smirnov Test:
500 '                      "Report Title"
510 '                      #Observations,Y1,Y2,Y3, . . .
520 '
530 KEY OFF : OPTION BASE 1
540 CLS : CLEAR : PRINT "Statistical Analysis Package"
550 DEFINT H-L,N,R : DEFDBL B,E,M,S,T,X,Y
560 PRINT : PRINT
570 PRINT "1) One-way ANOVA"
580 PRINT "2) Two-way ANOVA"
590 PRINT "3) Multiple Regression"
600 PRINT "4) Factorial Analysis"
610 PRINT "5) Kolmogorov-Smirnov Test"
620 PRINT "6) Distribution Percentiles"
630 PRINT "7) Exit to BASIC"
640 PRINT "8) Exit to DOS"
650 PRINT : INPUT "Enter selection: ",I
660 IF I>8 THEN BEEP : GOTO 540
670 IF I=6 THEN 3050
680 IF I=7 THEN CLS : KEY ON : END
690 IF I=8 THEN CLS : SYSTEM
700 INPUT "Enter name of data file: ",F$
710 OPEN F$ FOR INPUT AS #1
720 INPUT "Do you want output to go to disk? (Y/N): ",Q$
730 IF Q$<>"Y" AND Q$<>"y" THEN 760
740 INPUT "Enter name of output file: ",DUMP$
750 OPEN DUMP$ FOR APPEND AS #2
760 ON I GOTO 800,1030,1710,2020,2570
770 '
780 '  Subprogram:  One-way Analysis of Variance
790 '
800 INPUT #1,RU,RP : RE=RU : RR=RU*RP : H=1
810 DIM E(RR),LA$(RU),M(RU),S(RU),T(RU),Y(RU,RP,1)
820 INPUT #1,TI$(H)
830 FOR I=1 TO RU : INPUT #1,LA$(I) : NEXT
840 FOR I=1 TO RU
850   FOR J=1 TO RP
860     INPUT #1,Y(I,J,1)
870     T(I)=T(I)+Y(I,J,1)
880     SS=SS+Y(I,J,1)*Y(I,J,1)
890   NEXT
900   SSR=SSR+T(I)*T(I)/RP
910   M(I)=T(I)/RP
920   TT=TT+T(I)
930 NEXT
940 CLOSE #1
950 CLS : GOSUB 3290 : GOSUB 5030   ' Print ANOVA table
960 CLS : GOSUB 3990   ' Bartlett's test
970 GOSUB 4300 : GOSUB 5030   ' Plot residuals
980 CLS : GOSUB 4430   ' Duncan's test
990 GOSUB 5030 : CLOSE #2 : GOTO 540
1000 '
```

```
1010 '   Subprogram:   Two-way Analysis of Variance
1020 '
1030 INPUT #1,RA,RB,RP
1040 RU=RA*RB : RAR=RA*RP : RBR=RB*RP : RR=RA*RB*RP : H=1
1050 DIM E(RR),M(RU),S(RU),T(RU),TA(RA),TB(RB),Y(RU,RP,1)
1060 INPUT #1,TI$,LA$,LB$
1070 FOR I=1 TO RA
1080   FOR J=1 TO RB
1090     K=RB*(I-1)+J
1100     FOR L=1 TO RP
1110       INPUT #1,Y(K,L,1)
1120       T(K)=T(K)+Y(K,L,1)
1130       SS=SS+Y(K,L,1)*Y(K,L,1)
1140     NEXT
1150     M(K)=T(K)/RP
1160     TT=TT+T(K)
1170 NEXT : NEXT
1180 CLOSE #1
1190 FOR I=1 TO RA
1200   FOR J=1 TO RB
1210     K=RB*(I-1)+J
1220     TA(I)=TA(I)+T(K)
1230     SSR=SSR+T(K)*T(K)/RP
1240   NEXT
1250   SSA=SSA+TA(I)*TA(I)/RBR
1260 NEXT
1270 FOR J=1 TO RB
1280   FOR I=1 TO RA
1290     K=RB*(I-1)+J
1300     TB(J)=TB(J)+T(K)
1310   NEXT
1320   SSB=SSB+TB(J)*TB(J)/RAR
1330 NEXT
1340 TTT=TT*TT/RR : SST=SS-TTT : SSR=SSR-TTT : SSE=SST-SSR
1350 SSA=SSA-TTT : SSB=SSB-TTT : SSAB=SSR-SSA-SSB
1360 MSA=SSA/(RA-1) : MSB=SSB/(RB-1) : MSAB=SSAB/((RA-1)*(RB-1))
1370 MSE=SSE/(RU*(RP-1)) : FA=MSA/MSE : FB=MSB/MSE : FAB=MSAB/MSE
1380 N1=RA-1 : N2=RU*(RP-1) : Z1=FA : GOSUB 5450 : P1=P
1390 N1=RB-1 : N2=RU*(RP-1) : Z1=FB : GOSUB 5450 : P2=P
1400 N1=(RA-1)*(RB-1) : N2=RU*(RP-1) : Z1=FAB : GOSUB 5450 : P3=P
1410 Z2=SSA : Z3=MSA : Z4=SSB : Z5=MSB : Z6=SSAB : Z7=MSAB
1420 Z8=SSE : Z9=MSE : Z10=SST   ' Single precision
1430 CLS : PRINT TI$ : PRINT : PRINT
1440 PRINT "Source          |      SS      df      MS          F*
1450 PRINT "------------|---------------------------------------
1460 PRINT LA$;TAB(13);"| ";Z2;TAB(27);RA-1;TAB(33);Z3;
1470 PRINT TAB(45);FA;TAB(57) : PRINT USING "p = .####";P1
1480 PRINT LB$;TAB(13);"| ";Z4;TAB(27);RB-1;TAB(33);Z5;
1490 PRINT TAB(45);FB;TAB(57) : PRINT USING "p = .####";P2
1500 PRINT "Interaction | ";Z6;TAB(27);(RA-1)*(RB-1);TAB(33)
1510 PRINT Z7;TAB(45);FAB;TAB(57) : PRINT USING "p = .####";P3
1520 PRINT "Error         | ";Z8;TAB(27);RU*(RP-1);TAB(33);Z9
1530 PRINT "------------|---------------------------------------
```

```
1540 PRINT "Total      | ";Z10;TAB(27);RR-1
1550 PRINT : PRINT USING "R-Square = .####";SSR/SST; : PRINT TAB(22)
1560 PRINT USING "Adjusted R-Square = .####";1-(RR-1)*SSE/((RU*(RP-1))*SST)
1570 GOSUB 5030 : CLS : GOSUB 3990  ' Bartlett's test
1580 GOSUB 4300 : GOSUB 5030. ' Plot residuals
1590 CLS : PRINT "Treatment Means:" : PRINT
1600 FOR I=1 TO RA
1610   PRINT "A(";MID$(STR$(I),2);"):  ";TA(I)/RBR
1620 NEXT
1630 FOR I=1 TO RB
1640   PRINT "B(";MID$(STR$(I),2);"):  ";TB(I)/RAR
1650 NEXT
1660 PRINT "Grand: ";TT/RR
1670 GOSUB 5030 : CLOSE #2 : GOTO 540
1680 '
1690 '  Subprogram:  Multiple Regression
1700 '
1710 INPUT #1,RE,RR : RE=RE+1 : H=1
1720 DIM B(RE),LA$(RE),X(RR,RE),XTX(RE,RE),XTXI(RE,RE),XTY(RE),Y(RR)
1730 INPUT #1,TI$(H)
1740 FOR I=2 TO RE : INPUT #1,LA$(I) : NEXT
1750 FOR I=1 TO RR
1760   INPUT #1,Y(I)
1770   X(I,1)=1#  ' Double precision
1780   FOR J=2 TO RE
1790     INPUT #1,X(I,J)
1800 NEXT : NEXT
1810 CLOSE #1
1820 GOSUB 3610  ' Compute X Transpose X Inverse
1830 PRINT "Computing X Transpose Y . . ."
1840 FOR I=1 TO RE
1850   FOR J=1 TO RR
1860     XTY(I)=XTY(I)+X(J,I)*Y(J)
1870 NEXT : NEXT
1880 FOR I=1 TO RE   ' Compute Betas
1890   FOR J=1 TO RE
1900     B(I)=B(I)+XTXI(I,J)*XTY(J)
1910 NEXT : NEXT
1920 FOR I=1 TO RR   ' Compute sum of squares and total
1930   SS=SS+Y(I)*Y(I) : TT=TT+Y(I)
1940 NEXT
1950 FOR I=1 TO RE : SSR=SSR+B(I)*XTY(I) : NEXT
1960 CLS : GOSUB 3290 : PRINT   ' Print ANOVA table
1970 PRINT : GOSUB 3470   ' Print Beta table
1980 GOSUB 5030 : CLOSE #2 : GOTO 540
1990 '
2000 '  Subprogram:  Factorial Analysis
2010 '
2020 INPUT #1,RD,RE,RU,RP : RR=RU*RP
2030 DIM B(RE),X(RR,RE),XTX(RE,RE),XTXI(RE,RE),XTY(RE)
2040 DIM Y(RU,RP,RD),E(RR),TI$(RD),LA$(RE),M(RU),S(RU),T(RU)
2050 FOR I=1 TO RD : INPUT #1,TI$(I) : NEXT
2060 FOR I=2 TO RE : INPUT #1,LA$(I) : NEXT
```

```
2070 FOR I=1 TO RR
2080   FOR J=1 TO RE
2090     INPUT #1,X(I,J)
2100 NEXT : NEXT
2110 FOR I=1 TO RU
2120   FOR J=1 TO RP
2130     FOR K=1 TO RD
2140       INPUT #1,Y(I,J,K)
2150 NEXT : NEXT : NEXT
2160 CLOSE #1
2170 PRINT "Is your design matrix orthognal?"
2180 PRINT "(An orthogonal design runs much faster.)"
2190 INPUT "If you're not sure enter N (Y/N): ",K$
2200 IF K$<>"Y" AND K$<>"y" THEN GOSUB 3610 : GOTO 2230
2210 X=1#/RR
2220 FOR I=1 TO RE : XTXI(I,I)=X : NEXT  ' Short-cut for XTXI
2230 FOR H=1 TO RD  ' Perform stats for each dependent variable
2240 PRINT "Computing X Transpose Y . . ."
2250 FOR I=1 TO RE
2260   XTY(I)=0#
2270   FOR J=1 TO RU
2280     FOR K=1 TO RP
2290       L=RP*(J-1)+K
2300       XTY(I)=XTY(I)+X(L,I)*Y(J,K,H)
2310 NEXT : NEXT : NEXT
2320 FOR I=1 TO RE   ' Compute Betas
2330   B(I)=0#
2340   FOR J=1 TO RE
2350     B(I)=B(I)+XTXI(I,J)*XTY(J)
2360 NEXT : NEXT
2370 SS=0# : TT=0#   ' Compute elements of ANOVA table
2380 FOR I=1 TO RU
2390   T(I)=0#
2400   FOR J=1 TO RP
2410     T(I)=T(I)+Y(I,J,H) : SS=SS+Y(I,J,H)*Y(I,J,H)
2420   NEXT
2430   M(I)=T(I)/RP : TT=TT+T(I)
2440 NEXT
2450 SSR=0#
2460 FOR I=1 TO RE : SSR=SSR+B(I)*XTY(I) : NEXT
2470 CLS : GOSUB 3290 : GOSUB 5030   ' Print ANOVA table
2480 CLS : GOSUB 3470 : GOSUB 5030   ' Print Beta table
2490 CLS : GOSUB 3990  ' Bartlett's test
2500 GOSUB 4300 : GOSUB 5030   ' Plot residuals
2510 CLS : NEXT H  ' Do next dependent variable
2520 CLOSE #2 : GOTO 540
2530 '
2540 '   Subprogram:  A Kolmogorov-Smirnov Test for
2550 '   goodness-of-fit to a Normal distribution
2560 '
2570 INPUT #1,TI$,N  ' Read title and number of values
2580 DIM Y(N)
2590 FOR I=1 TO N
```

```
2600    INPUT #1,Y(I)   ' Read values
2610    T=T+Y(I)
2620 NEXT
2630 CLOSE #1
2640 M=T/N   ' Compute mean
2650 CLS : PRINT "Kolmogorov-Smirnov Test"
2660 PRINT : PRINT : PRINT TI$
2670 PRINT : Z=M : PRINT "Mean =";Z
2680 FOR I=1 TO N  ' Compute sum of squares
2690    SS=SS+((Y(I)-M)*(Y(I)-M))
2700 NEXT
2710 S=SQR(SS/(N-1))
2720 Z=S : PRINT "SDev =";Z : PRINT
2730 PRINT "Do you wish to supply your own parameters? (Y/N)"
2740 K$=INKEY$ : IF K$="" THEN 2740
2750 IF K$<>"Y" AND K$<>"y" THEN 2810
2760 LOCATE 9
2770 PRINT "Check against parameters:                           "
2780 INPUT "Mean: ",M
2790 INPUT "Standard deviation: ",S
2800 GOTO 2830
2810 LOCATE 9
2820 PRINT "Checking against estimated parameters.             "
2830 FOR I=1 TO N
2840    Y(I)=(Y(I)-M)/S  ' Normalize values
2850    Z1=Y(I) : GOSUB 5820 : Y(I)=1-P  ' Replace w/ cumulative Normal
2860 NEXT
2870 LIM=N-1   ' Bubble sort cumulative values
2880 FLAG=0
2890 FOR I=1 TO LIM
2900    IF Y(I)<=Y(I+1) THEN 2930
2910    YY=Y(I) : Y(I)=Y(I+1) : Y(I+1)=YY
2920    FLAG=1 : LIM=I
2930 NEXT
2940 IF FLAG=1 THEN 2880
2950 FOR I=1 TO N  ' Compute Dmax
2960    D1=I/N-Y(I) : D2=Y(I)-(I-1)/N
2970    IF D1>DM THEN DM=D1
2980    IF D2>DM THEN DM=D2
2990 NEXT
3000 PRINT : PRINT "Dmax =";DM
3010 GOSUB 5030 : CLOSE #2 : GOTO 540
3020 '
3030 '   Subprogram:  Distribution Percentiles
3040 '
3050 CLS : PRINT "One-tailed Distribution Percentiles"
3060 PRINT : PRINT
3070 PRINT "1) Chi-square"
3080 PRINT "2) F Distribution"
3090 PRINT "3) Standard Normal"
3100 PRINT "4) Student's t"
3110 PRINT "5) Return to Main Menu"
3120 LOCATE 10 : INPUT "Enter selection: ",I
```

```
3130 IF I>5 THEN BEEP : GOTO 3050
3140 ON I GOTO 3150,3170,3190,3200,540
3150 INPUT "Enter degrees of freedom & statistic (v,X*): ",N1,Z1
3160 GOSUB 5190 : GOTO 3220
3170 INPUT "Enter degrees of freedom and statistic (v1,v2,F*): ",N1,N2,Z1
3180 GOSUB 5450 : GOTO 3220
3190 INPUT "Enter test statistic (Z*): ",Z1 : GOSUB 5820 : GOTO 3220
3200 INPUT "Enter degrees of freedom and statistic (v,t*): ",N1,Z1
3210 GOSUB 5960
3220 PRINT USING "p = .####";P
3230 LOCATE 23 : PRINT "Press any key to continue."
3240 K$=INKEY$ : IF K$="" THEN 3240
3250 GOTO 3050
3260 '
3270 '  Subroutine:  Print ANOVA table
3280 '
3290 TTT=TT*TT/RR : SST=SS-TTT : SSR=SSR-TTT : SSE=SST-SSR
3300 N1=RE-1 : N2=RR-RE : MSR=SSR/N1 : MSE=SSE/N2
3310 Z1=MSR/MSE : GOSUB 5450  ' Compute p-value for F statistic
3320 Z2=SSR : Z3=MSR : Z4=SSE : Z5=MSE : Z6=SST  ' Single precision
3330 PRINT TI$(H) : PRINT : PRINT
3340 PRINT "Source          SS        df        MS          F*
3350 PRINT "-----------|-----------------------------------------
3360 PRINT "Regression | ";Z2;TAB(27);RE-1;TAB(33);Z3;
3370 PRINT TAB(45);Z1;TAB(57) : PRINT USING "p = .####";P
3380 PRINT "Error      | ";Z4;TAB(27);RR-RE;TAB(33);Z5
3390 PRINT "-----------|-----------------------------------------
3400 PRINT "Total      | ";Z6;TAB(27);RR-1
3410 PRINT : PRINT USING "R-Square = .####";SSR/SST; : PRINT TAB(22)
3420 PRINT USING "Adjusted R-Square = .####";1-(RR-1)*SSE/((RR-RE)*SST)
3430 RETURN
3440 '
3450 '  Subroutine:  Print regression  coefficients
3460 '
3470 PRINT "Effect";TAB(19);"Beta";TAB(32);"Std Error";
3480 PRINT TAB(50);"t*";TAB(63);"p"
3490 PRINT "------";TAB(19);"----";TAB(32);"---------";
3500 PRINT TAB(50);"--";TAB(63);"-"
3510 Z=B(1) : PRINT "Mean";TAB(16);Z
3520 FOR I=2 TO RE
3530   N1=RR-RE : Z2=B(I) : Z3=SQR(MSE*XTXI(I,I)) : Z1=B(I)/Z3
3540   PRINT LA$(I);TAB(16);Z2;TAB(31);Z3;TAB(46);Z1;TAB(61)
3550   GOSUB 5960 : PRINT USING ".####";2*P  ' 2-tailed t
3560 NEXT
3570 RETURN
3580 '
3590 '  Subroutine:  Compute X Transpose X Inverse
3600 '
3610 PRINT "Computing X Transpose X . . ."
3620 FOR I=1 TO RE
3630   FOR J=1 TO RE
3640     FOR K=1 TO RR
3650       XTX(I,J)=XTX(I,J)+X(K,I)*X(K,J)
```

```
3660 NEXT : NEXT : NEXT
3670 PRINT "Computing X Transpose X Inverse . . ."
3680 FOR I=1 TO RE  ' Create an identity matrix
3690    XTXI(I,I)=1#
3700 NEXT
3710 FOR K=1 TO RE
3720    XX=0#
3730    FOR I=K TO RE  ' Find largest element in XTX column
3740       IF XX<ABS(XTX(I,K)) THEN XX=ABS(XTX(I,K)) : L=I
3750    NEXT
3760    IF L=K THEN 3820  ' If current row then skip
3770    FOR J=1 TO RE  ' Interchange rows K and L
3780       XX=XTX(K,J) : YY=XTXI(K,J)
3790       XTX(K,J)=XTX(L,J) : XTXI(K,J)=XTXI(L,J)
3800       XTX(L,J)=XX : XTXI(L,J)=YY
3810    NEXT
3820    FOR I=1 TO RE  ' Perform eliminations
3830       IF I=K THEN 3890
3840       XX=-XTX(I,K)/XTX(K,K)
3850       FOR J=1 TO RE
3860          XTX(I,J)=XTX(I,J)+XX*XTX(K,J)
3870          XTXI(I,J)=XTXI(I,J)+XX*XTXI(K,J)
3880       NEXT
3890    NEXT I
3900    XX=1/XTX(K,K)
3910    FOR J=1 TO RE  ' Turn XTX(K,K) into a 1
3920       XTX(K,J)=XX*XTX(K,J) : XTXI(K,J)=XX*XTXI(K,J)
3930    NEXT
3940 NEXT K
3950 RETURN
3960 '
3970 '   Subroutine:  Compute Bartlett's statistic
3980 '
3990 EMAX=0 : MMIN=1E+09 : MMAX=0
4000 FOR I=1 TO RU  ' Compute sample variances and residuals
4010    S(I)=0
4020    FOR J=1 TO RP
4030       K=RP*(I-1)+J
4040       E(K)=Y(I,J,H)-M(I)
4050       IF M(I)<MMIN THEN MMIN=M(I)
4060       IF M(I)>MMAX THEN MMAX=M(I)
4070       IF ABS(E(K))>EMAX THEN EMAX=ABS(E(K))
4080       S(I)=S(I)+E(K)*E(K)
4090    NEXT
4100    S(I)=S(I)/(RP-1)
4110 NEXT
4120 SP=0 : Q=0
4130 FOR I=1 TO RU  ' Compute Bartlett variables
4140    SP=SP+S(I)
4150    IF S(I)=0 THEN Q=Q-3 : GOTO 4170
4160    Q=Q+LOG(S(I))
4170 NEXT
4180 SP=SP/RU
```

```
4190 Q=.4342945*(RP-1)*(RU*LOG(SP)-Q)   ' .43..converts Ln to Log
4200 C=1+(RU+1)/(3*RU*(RP-1))
4210 Z1=2.3026*Q/C
4220 N1=RU-1 : GOSUB 5190   ' Compute p-value for Chi-square
4230 PRINT "Bartlett's test for homogeneity of variance:"
4240 PRINT "Chi-square =";Z1;TAB(26);"df =";RU-1;TAB(36)
4250 PRINT USING "p = .####";P
4260 RETURN
4270 '
4280 '   Subroutine:  Plot residuals
4290 '
4300 PRINT : PRINT : FOR I=1 TO 15 : PRINT TAB(10);"|" : NEXT
4310 LOCATE 12 : PRINT "Residual   -------------------------";
4320 PRINT "---------------------- Fitted"
4330 FOR I=1 TO RU
4340   FOR J=1 TO RP
4350     K=12-7*E(RP*(I-1)+J)/EMAX   ' Y coordinate
4360     L=13+43*(M(I)-MMIN)/(MMAX-MMIN)   ' X coordinate
4370     LOCATE K,L : PRINT "*"
4380 NEXT : NEXT
4390 RETURN
4400 '
4410 '   Subroutine:  Duncan's Multiple Range Test
4420 '
4430 PRINT "Duncan's Multiple Range Test (p=.05)" : PRINT
4440 PRINT TAB(19);"Mean         Variance"
4450 PRINT TAB(19);"----         --------"
4460 FOR I=1 TO RU
4470   Z1=M(I) : Z2=S(I)   ' Single precision
4480   PRINT MID$(STR$(I),2);". ";LA$(I);TAB(17);Z1;TAB(29);Z2
4490 NEXT
4500 DATA 18.0,6.09,4.50,3.93,3.64,3.46,3.35,3.26,3.20,3.15,3.11,3.08,3.06
4510 DATA 3.03,3.01,3.00,2.98,2.97,2.96,2.95,2.89,2.86,2.83,2.80,2.77
4520 DATA 18.0,6.09,4.50,4.01,3.74,3.58,3.47,3.39,3.34,3.30,3.27,3.23,3.21
4530 DATA 3.18,3.16,3.15,3.13,3.12,3.11,3.10,3.04,3.01,2.98,2.95,2.92
4540 DATA 18.0,6.09,4.50,4.02,3.79,3.64,3.54,3.47,3.41,3.37,3.35,3.33,3.30
4550 DATA 3.27,3.25,3.23,3.22,3.21,3.19,3.18,3.12,3.10,3.08,3.05,3.02
4560 DATA 18.0,6.09,4.50,4.02,3.83,3.68,3.58,3.52,3.47,3.43,3.39,3.36,3.35
4570 DATA 3.33,3.31,3.30,3.28,3.27,3.26,3.25,3.20,3.17,3.14,3.12,3.09
4580 DATA 18.0,6.09,4.50,4.02,3.83,3.68,3.60,3.55,3.50,3.46,3.43,3.40,3.38
4590 DATA 3.37,3.36,3.34,3.33,3.32,3.31,3.30,3.25,3.22,3.20,3.18,3.15
4600 DATA 18.0,6.09,4.50,4.02,3.83,3.68,3.61,3.56,3.52,3.47,3.44,3.42,3.41
4610 DATA 3.39,3.38,3.37,3.36,3.35,3.35,3.34,3.29,3.27,3.24,3.22,3.19
4620 DATA 18.0,6.09,4.50,4.02,3.83,3.68,3.61,3.56,3.52,3.47,3.45,3.44,3.42
4630 DATA 3.41,3.40,3.39,3.38,3.37,3.37,3.36,3.32,3.30,3.28,3.26,3.23
4640 DATA 18.0,6.09,4.50,4.02,3.83,3.68,3.61,3.56,3.52,3.47,3.46,3.44,3.44
4650 DATA 3.42,3.42,3.41,3.40,3.39,3.39,3.38,3.35,3.33,3.31,3.29,3.26
4660 DATA 18.0,6.09,4.50,4.02,3.83,3.68,3.61,3.56,3.52,3.47,3.46,3.46,3.45
4670 DATA 3.44,3.43,3.43,3.42,3.41,3.41,3.40,3.37,3.35,3.33,3.32,3.29
4680 DIM NDX(RU),A1(RU,25),A2(RU)
4690 FOR I=1 TO RU : NDX(I)=I : NEXT
4700 LIM=RU-1   ' Bubble sort means and indexes
4710 FLAG=0
```

```
4720 FOR I=1 TO LIM
4730    IF M(I)<=M(I+1) THEN 4780
4740    MM=M(I) : NN=NDX(I)
4750    M(I)=M(I+1) : NDX(I)=NDX(I+1)
4760    M(I+1)=MM : NDX(I+1)=NN
4770    FLAG=1 : LIM=I
4780 NEXT
4790 IF FLAG=1 THEN 4710
4800 FOR I=2 TO RU : FOR J=1 TO 25 : READ A1(I,J) : NEXT : NEXT
4810 Z=SQR(MSE/RP) : DF=RR-RU
4820 PRINT : PRINT "Standard Error =";Z;"   df =";DF
4830 IF DF<=20 THEN 4890   ' For large df reset df to agree with data lines
4840 IF DF>20 AND DF<30 THEN DF=20
4850 IF DF>=30 AND DF<40 THEN DF=21
4860 IF DF>=40 AND DF<60 THEN DF=22
4870 IF DF>=60 AND DF<100 THEN DF=23
4880 IF DF>=100 AND DF<200 THEN DF=24 ELSE DF=25
4890 FOR I=2 TO RU : A2(I)=A1(I,DF)*Z : NEXT
4900 FOR I=RU TO 1 STEP -1
4910    FOR J=1 TO RU
4920       IF J>=I THEN 4980
4930       Z=M(I)-M(J)
4940       A$="<" : B$="Do not reject equal"
4950       IF Z>A2(I-J+1) THEN A$=">" : B$="Reject equal"
4960       PRINT MID$(STR$(NDX(I)),2);" vs.";NDX(J);":";Z;A$;A2(I-J+1);
4970       PRINT "(R"+MID$(STR$(I-J+1),2)+") "+B$
4980 NEXT : NEXT
4990 RETURN
5000 '
5010 '   Subroutine:  Save data screen if desired
5020 '
5030 IF Q$="Y" OR Q$="y" THEN 5070
5040 LOCATE 23 : PRINT "Press any key to continue."
5050 K$=INKEY$ : IF K$="" THEN 5050
5060 RETURN
5070 LOCATE 23 : PRINT "Saving data screen to disk . . ."
5080 FOR I=1 TO 22
5090    D$=""
5100    FOR J=1 TO 65
5110       D$=D$+CHR$(SCREEN(I,J))
5120    NEXT
5130    PRINT #2,D$
5140 NEXT
5150 RETURN
5160 '
5170 '   Subroutine:  Percentiles of the Chi-Square distribution
5180 '
5190 P=1 : IF Z1=0 THEN RETURN
5200 IF Z1<0 THEN PRINT "Warning! Negative Chi-Square!" : STOP
5210 IF N1=1 THEN Z1=SQR(Z1) : GOSUB 5820 : RETURN
5220 IF N1>50 OR Z1>100 THEN 5380
5230 Z2=Z1 : P1=.5*(N1-2) : Z3=.5*Z2 : P2=P1+2 : Z4=Z3/P2
5240 FOR I=1 TO 10000
```

```
5250    IF P=P+Z4 THEN 5280
5260    P=P+Z4 : P2=P2+1 : Z4=Z4*Z3/P2
5270 NEXT
5280 Z5=1
5290 IF N1-2*INT(N1/2)=1 THEN 5330  ' If N1 is odd then skip
5300 Z6=0  ' N1 is even
5310 FOR I=1 TO N1/2 : Z6=Z6+LOG(I) : NEXT
5320 Z5=EXP(Z6) : GOTO 5350
5330 FOR I=1 TO N1 STEP 2 : Z5=Z5*I*.5 : NEXT  ' N1 is odd
5340 Z5=Z5*1.772459
5350 Z7=(P1+1)*LOG(Z3)+LOG(P)-LOG(Z5)-Z3
5360 P=1 : IF Z7>-30 THEN P=1-EXP(Z7)
5370 RETURN
5380 Z7=N1 : P2=1/Z7 : Z2=Z1 : Z8=SQR(2*Z2) : Z9=SQR(2*Z7-1)
5390 Z10=1+1/(16*Z7*(Z7-1)) : Z11=(.25*P2)*(1+5*P2*(1-.625*P2))
5400 Z1=(Z8-Z9*Z10)/SQR(1-Z11) : GOSUB 5820 : IF Z1<0 THEN P=1-P
5410 RETURN
5420 '
5430 '   Subroutine:  Percentiles of the F distribution
5440 '
5450 P=0 : IF Z1=0 THEN P=1 : RETURN
5460 IF Z1<0 THEN PRINT "Warning! Negative F!" : STOP
5470 Z2=N2/(N2+N1*Z1) : Z3=N1+N2-2
5480 IF N1-2*INT(N1/2)=1 THEN 5560  ' If N1 is odd then skip
5490 N1=N1-2 : IF N1<=1 THEN 5530
5500 Z3=Z3-2 : P=(1-Z2)*Z3/N1*(1+P)
5510 IF P>1E+24 THEN 5530
5520 GOTO 5490
5530 Z4=(.5*N2)*LOG(Z2) : IF Z4>-60 THEN Z4=EXP(Z4) ELSE Z4=0
5540 P=Z4*(1+P) : IF P<0 THEN P=0
5550 RETURN
5560 IF N2-2*INT(N2/2)=1 THEN 5630  ' If N2 is odd then skip
5570 N2=N2-2 : IF N2<1 THEN 5600
5580 Z3=Z3-2 : P=Z2*Z3/N2*(1+P) : IF P>1E+24 THEN 5600
5590 GOTO 5570
5600 Z4=(.5*N1)*LOG(1-Z2) : IF Z4>-60 THEN Z4=EXP(Z4) ELSE Z4=0
5610 P=1-Z4*(1+P) : IF P<0 THEN P=0
5620 RETURN
5630 Z5=ATN(SQR(N1*Z1/N2))  ' N1 & N2 are both odd
5640 Z6=0 : Z7=0 : N3=INT(N2/2) : N4=N2
5650 Z8=SIN(Z5) : Z9=COS(Z5) : Z10=Z8*Z8 : Z11=Z9*Z9
5660 IF N2<=1 THEN 5700
5670 N2=N2-2 : IF N2<=2 THEN 5690
5680 Z6=Z11*(N2-1)/N2*(1+Z6) : GOTO 5670
5690 Z6=Z8*Z9*(1+Z6)
5700 Z6=Z5+Z6 : IF N1<=1 THEN 5730
5710 N1=N1-2 : IF N1<=2 THEN 5730
5720 Z3=Z3-2 : Z7=Z10*Z3/N1*(1+Z7) : GOTO 5710
5730 IF N3<1 THEN 5760
5740 Z12=1
5750 FOR I=1 TO N3 : Z12=Z12*I/(I-.5) : NEXT
5760 Z4=N4*LOG(Z9) : IF Z4>-60 THEN Z4=EXP(Z4) ELSE Z4=0
5770 Z7=Z12*Z8*Z4*(1+Z7) : P=1+.6366198*(Z7-Z6) : IF P<0 THEN P=0
```

```
5780 RETURN
5790 '
5800 '   Subroutine:   Percentiles of the Normal distribution
5810 '
5820 IF Z1>5 THEN P=0 : RETURN
5830 IF Z1<-5 THEN P=1 : RETURN
5840 C1=4.986735E-02 : C2=2.114101E-02 : C3=3.277626E-03
5850 C4=3.80036E-05 : C5=4.88906E-05 : C6=5.383E-06
5860 Z2=ABS(Z1)
5870 P=C1+Z2*(C2+Z2*(C3+Z2*(C4+Z2*(C5+Z2*C6))))
5880 P=16*LOG(1+Z2*P)
5890 IF P<-30 THEN P=-30
5900 IF P>30 THEN P=30
5910 P=.5/EXP(P) : IF Z1<0 THEN P=1-P
5920 RETURN
5930 '
5940 '   Subroutine:   Percentiles of the t distribution
5950 '
5960 C=.6366198 : Z2=1/(1+Z1*Z1/N1) : Z3=Z1/SQR(N1)
5970 IF N1-2*INT(N1/2)=1 THEN 6000   ' If N1 is odd then skip
5980 Z4=Z3*SQR(Z2) : P=1-Z4 : IF N1=2 THEN 6070
5990 N2=1 : GOTO 6030
6000 P=1-C*ATN(Z3) : IF N1=1 THEN 6070   ' N1 is odd
6010 Z4=C*Z3*Z2 : P=P-Z4 : IF N1=3 THEN 6070
6020 N2=0
6030 N3=INT((N1-2)/2)
6040 FOR J=1 TO N3
6050    N4=2*J-N2 : Z4=Z4*Z2*N4/(N4+1) : P=P-Z4
6060 NEXT
6070 IF P<0 THEN P=0
6080 P=P/2 : IF Z1<0 THEN P=1-P
6090 RETURN
```

VITA

Captain Joseph B. Niemeyer was born on 28 April 1955 in St. John's, Newfoundland. Upon graduation from Chariho Regional High School in Wood River Junction, Rhode Island, in 1973, he attended the United States Air Force Academy in Colorado Springs, Colorado. In 1977, he graduated from the Air Force Academy with a Bachelor of Science degree in Biology. After attending Undergraduate Pilot Training at Laughlin AFB, Texas, he was assigned to the 14th Military Airlift Squadron, 63rd Military Airlift Wing, Norton AFB, California. While assigned to the 63rd Military Airlift Wing, Captain Niemeyer's duties included: aircraft commander in the C-141B Starlifter aircraft, instructor pilot, flight examiner, and Chief of Aircrew Standardization/Evaluation. In August 1983, he was assigned to the School of Engineering, Air Force Institute of Technology, Wright-Patterson AFB, Ohio, as a resident student in the Strategic and Tactical Sciences Program.

                                    Permanent Address: 3324 Milton Avenue
                                                         Dallas, Texas   75205

VITA

Captain Michael D. Selva was born on 9 September 1955 in Biloxi, Mississippi. Upon graduation from the Lajes Dependent's High School in Lajes Field, Azores, Portugal, in 1973, he attended the United States Air Force Academy. In 1977, he graduated from the Air Force Academy with a Bachelor of Science degree in Military History. After completing Missile Launch Officer technical training at Vandenberg AFB, California, he was assigned to the 321st Strategic Missile Wing, Grand Forks AFB, North Dakota. While assigned to the 321st Strategic Missile Wing, Captain Selva's duties included: Senior Instructor Deputy Missile Combat Crew Commander, Missile Combat Crew Commander, Wing Standardization/Evaluation Missile Combat Crew Commander, Emergency War Order (EWO) Instructor, ICBM Plans Officer, Chief, ICBM Plans Branch, and Chief, Emergency War Order (EWO) Training Branch. In August 1983, he was assigned to the School of Engineering, Air Force Institute of Technology, Wright-Patterson AFB, Ohio, as a resident student in the Strategic and Tactical Sciences Program.

Permanent Address: 1352 Fry Lane
Hayward, California 94545

END

FILMED

8-85

DTIC